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# AGRICULTURE 4.0: NEW PERSPECTIVES FOR AGRICULTURAL SUSTAINABILITY IN ROMANIA

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***Abstract:*** *Agriculture faces mounting pressure due to climate change, resource scarcity, demographic shifts, and food waste. To address these challenges, a whole farm management approach is crucial, involving collaboration between stakeholders, infrastructure, and technology. Agriculture 4.0 emerges as a key solution, aiming to improve sustainability by integrating advanced technologies like Cloud Computing, IoT, AI, Robotics, Big Data, and Data Analytics. These innovations enable informed decision-making across various sectors, enhancing productivity while ensuring environmental safety and stakeholder well-being. Implementing efficient processes at reduced costs is essential, requiring coordinated efforts from farmers, agronomists, and policymakers. Agriculture 4.0 promotes synergy between these actors, improving farm management and fostering sustainable practices. This study aims to explore Agriculture 4.0's role in Romania, assessing its technological capabilities, impacts, and challenges in sustainable agriculture. While these advancements promise to revolutionize the sector, challenges like data security, technological accessibility, and social impacts must be carefully managed to ensure a balanced and responsible transformation.*

***Keywords:*** *sustainability, agriculture 4.0, software, economic efficiency, rural development.*

## 1. INTRODUCTION

Agriculture 4.0 represents a significant phase in the evolution of the agricultural sector and was triggered by the introduction of a set of digital technologies in the early 2010s, and [1] suggest that these technologies include “cheap and improved sensors and actuators, low-cost microprocessors, high-bandwidth cellular communications, cloud-based ICT systems and Big Data analytics”, concluding that “agriculture has entered a new era as a result of the adoption of these technologies called Agriculture 4.0”.

Beluhova-Uzunova et al. [2] state that “Agriculture 4.0 is a concept for the future of agriculture and the sustainable development of the agricultural sector, affirming the paradigm between its potential to increase global food production, which is essential to meet the demands of a growing population estimated at 9 billion people by 2050”. It is clear that digital technologies have already improved the productivity of agricultural operations and that the shift towards Agriculture 4.0 benefits not only farmers but also the sustainable development of the primary sector. However, it is important to underline that, despite its relevance, Agriculture 4.0 is a concept still unclearly defined in the scientific literature, and the existence of several terms and perspectives from which it can be approached underlines its complexity. Some definitions refer to “Agriculture 4.0 as an evolution of precision agriculture, extending beyond field variability to include context awareness”, while other perspectives see Agriculture 4.0 as “an application of Industry 4.0 principles to agriculture”, using smart and digital technologies such as sensors to manage and analyse data generated by agricultural operations.

According to [3], “Agriculture 4.0 is already in full swing, encompassing operational technologies such as robotics, nanotechnology, protein synthesis, cellular agriculture, gene-editing technology, artificial intelligence, blockchain and machine learning (ML)”, all of which will have a pervasive and significant

impact on food production systems and the future of agriculture. The authors highlighted the importance placed on responsible technology selection and inclusion towards "sustainable agriculture and innovative food systems", emphasizing that responsible innovation processes are crucial to anticipate the potential impact of Agriculture 4.0, with a particular focus on inclusive processes.

Rose et al. [4] found that the Agriculture 4.0 narrative focused primarily on improving productivity and protecting the environment, while generating significant positive and negative social impacts. This underlines the need for greater involvement of people in agricultural innovation processes, which must be carried out under the umbrella of responsible principles, with a view to social sustainability.

Lajoie-O'Malley et al. [5] highlighted the significant impact of digital technologies on service delivery in food ecosystems. Braun, Colangelo and Steckel [6] demonstrated that innovations in supply chain management not only address the intrinsic problems of agricultural production within the Farming 4.0 model, but also create a basis for the development of new forms of work and business.

The sustainability of supply chains for agri-food products has been analysed by [7], who identified interventions to improve supply chain management and logistics processes in the context of Farming 4.0. Lezoche et al. [8] conducted a comprehensive literature review detailing the many technologies available in agrifood supply chains within the Agriculture 4.0 philosophy. Similarly, [9] described how S3 (sensory, smart and sustainable) technologies have contributed to the systematic creation of new products in agrifood 4.0 supply chains.

Belaud et al. [10] highlighted the use of Big Data for sustainable supply chain management for bioenergy production, highlighting the revolutionary potential of using Big Data in combination with Industry 4.0 technologies in agricultural waste management. Annosi et al. [11] assessed the impact of 4.0 technologies in smart agriculture, highlighting the benefits that these technologies can bring to small and medium-sized farmers, particularly in supporting their decision-making process.

Torky and Hassanein [12] presented the integration of blockchain with the Internet of Things (IoT) for implementing agricultural data analytics systems, developing an intelligent peer-to-peer (P2P) system capable of verifying, securing, monitoring and analyzing information for precision agriculture applications. The digitisation of agriculture focuses on the management of on-farm and off-farm agricultural activities. This involves collecting and analysing data from a variety of sources such as sensors, farm machinery, drones and satellites. This data is used to monitor and control issues such as soil, water, animals and human factors involved in the agricultural process. One of the significant aspects of digitisation is the ability to interpret data to understand the past and predict the future. This allows farmers to make faster and more accurate decisions by having access to real-time information or relevant historical data. Through constant monitoring and analysis of specific data, the agricultural sector can progress and better adapt to the changing demands of modern agriculture.

The aim of this study is to investigate and assess the prospects of Agriculture 4.0 in terms of sustainability of the agricultural system in Romania by analysing and identifying specific technologies and key solutions associated with Agriculture 4.0, investigating the technological capabilities of these solutions including their degree of effectiveness in optimising agricultural processes and enhancing sustainability, examining the impact of the use of Agriculture 4.0 technologies on the agricultural system in Romania, including aspects such as yield, resource efficiency and environmental impact reduction, and formulating solutions and recommendations for effectively managing the identified challenges and optimising the benefits of Agriculture 4.0 within the agricultural system in Romania. By achieving these objectives, the study aims to provide a detailed and comprehensive picture of the current status of Agriculture 4.0 in Romanian agriculture, highlight opportunities and address potential barriers to an efficient and sustainable implementation of these technologies in agriculture.

## 2. RESEARCH METHODOLOGY

The study is based on a review of the literature on the prospects for the development of Agriculture 4.0 in the world and their translation into the Romanian agricultural system. The working methodology consisted in selecting and identifying scientific articles from 2018-2022 in the field of Agriculture 4.0 and Industry 4.0, sources from Google Schoolbar database and Web of Science platform. The data sources aimed to explore the origins and development of the term Agriculture 4.0, tracing how this concept has evolved over time, identify key events and significant contributions in defining and conceptualizing Agriculture 4.0, investigate how Industry 4.0 has influenced and transformed various industrial sectors, identify similarities and differences between the concept of Agriculture 4.0 and Industry 4.0, analyze how Industry 4.0 principles and technologies have been adapted and integrated into the specific context of agriculture. This methodology provides a comprehensive framework for investigating and understanding the depth of the impact of Agriculture 4.0 on the sustainability of the agricultural system in Romania, as well as for addressing the challenges and proposing solutions oriented towards a modern and viable agriculture in the future. The literature review is an essential step in the research process, providing a solid basis for understanding the historical and conceptual context of Agriculture 4.0, as well as the impact of Industry 4.0 on different industrial sectors. The selection of scientific papers in the researched area aimed at identifying and presenting the concept of Agriculture 4.0 in the context of the fourth industrial revolution, highlighting the parallels with "Industry 4.0", examining the origin of the term "Industry 4.0" and its influence on the development of agriculture, identifying key technologies associated with Agriculture 4. 0 such as big data, internet of things and artificial intelligence, analysing how these technologies are integrated into farm management for automation and optimisation, investigating how Agriculture 4.0 affects sustainable growth, highlighting benefits such as resource efficiency management, precise agricultural production and reduced environmental impact.

In addition to the bibliographic analysis, the research also included an application stage consisting of the development of a conceptual framework for the integration of 4.0 technologies in Romanian farms, with an emphasis on correlating them with sustainability indicators. Qualitative (content analysis of scientific sources) and quantitative (assessment of the degree of adoption of digital technologies in agriculture, through the processing of official statistical data and secondary data from national and European reports) analysis methods were used.

In the second stage, the research integrated a systemic conceptual modeling, representing the relationships between technologies (IoT, Big Data, AI, etc.) and economic and environmental outcomes (resource efficiency, loss reduction, productivity increase). An input-output analysis was used to assess the impact of technology implementation on yields and costs.

Perspectives of Agriculture 4.0 in the Romanian agricultural system aimed at analysing the maturity level of smart technologies in Romanian farms, assessing how these technologies are integrated in Romanian farm management towards the Agriculture 4.0 concept, identifying significant challenges related to the implementation of Agriculture 4.0 in the Romanian context and proposing perspectives and solutions for the development of responsive and adaptive farm management systems oriented towards the goals of modern sustainable agriculture as well as proposing recommendations for promoting Agriculture 4.0 in Romania and facilitating a successful transition towards a more efficient and sustainable agriculture.

## 3. RESULTS AND DISCUSSION

Smart and digital technologies are fundamental to Agriculture 4.0, as they enable the collection, integration and analysis of collected data. These technologies, such as cloud computing, allow farmers to manage and interpret data in real time, giving them the tools to make more informed and effective decisions.

This is a significant advance over the traditional approach based on experience and intuition.

Decisions made by farmers are traditionally based on personal experience and subjective beliefs about the environment, however, Agriculture 4.0 changes this paradigm, making farmers' decisions more informed and less based on intuition. The use of Decision Support Systems (DSS) and automatically collected data allows farmers to make fact-based decisions and integrate mathematical elements into the decision-making process, in addition, Agriculture 4.0 offers the possibility to automate some decisions through the concept of Cyber - Physical System (CPS), where smart devices connected to the Internet can manage certain aspects of the farm without direct human intervention. Agriculture 4.0 goes beyond the traditional boundaries of the agricultural holding, facilitating collaboration and data exchange between different actors in the food chain: suppliers of seeds, pesticides, veterinary services, agricultural consultants, sellers of agricultural equipment, financial service providers, inspections and customers.

Through digital technologies and data sharing, these actors can collaborate more effectively and provide better services to farmers. For example, better coordination with transport and processing companies can improve logistics and harvesting processes.

Also, agricultural equipment manufacturers can offer monitoring and maintenance services based on data generated by agricultural machinery. However, the concept of Agriculture 4.0 has not yet been holistically defined, and there are different perspectives from which it can be understood and analyzed (figure 1).

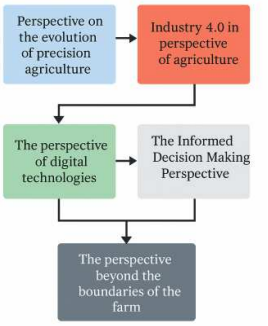


**Fig. 1.** Development perspectives of the concept of Agriculture 4.0.

The perspective of the evolution of precision agriculture within Agriculture 4.0 represents a fundamental approach that emphasizes the focus on optimizing and improving the management of agricultural resources through digital technologies (figure 2).

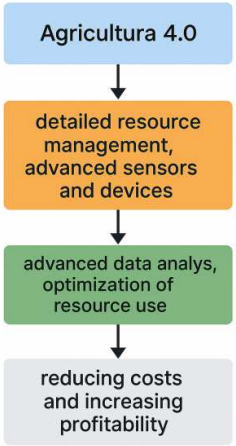


**Fig. 2.** Determinants of the evolution of precision agriculture in Agriculture 4.0.

Precision agriculture focuses on obtaining and using detailed and specific information to make better agricultural decisions by: collecting accurate data on soil, climate, moisture levels, plant condition and other relevant factors. Agriculture 4.0 brings advanced digital technologies that enable the collection and analysis of this data at unprecedented levels of detail.

Agriculture 4.0 brings with it a wide range of sensors and monitoring devices such as soil moisture sensors, weather sensors, drones and agricultural robots. These devices provide real-time data that allows farmers to monitor and manage every aspect of the farming process. An essential component of Agriculture 4.0 is the analysis of massive data (Big Data) to identify patterns and trends. Using artificial intelligence and machine learning algorithms, farmers can make more informed decisions about the optimal time to plant, irrigate and harvest based on the data collected. With this perspective, Agriculture 4.0 helps farmers use resources more efficiently. For example, irrigation can be adjusted according to the exact requirements of the plants, which reduces water consumption and costs.

By constantly monitoring and fine-tuning agricultural processes, Agriculture 4.0 helps reduce the waste of resources such as water and fertilizers. This has a positive impact on the environment, reducing unnecessary use of natural resources and carbon emissions. The detailed management of agricultural resources in the context of Agriculture 4.0 leads to an increase in the yield of crops and the improvement of the quality of agricultural products. Through precise application of fertilizers and other substances, higher and more consistent production can be achieved. By streamlining agricultural processes and reducing waste, Agriculture 4.0 can help reduce production costs and increase farm profitability.

The association of Agriculture 4.0 with the broader concept of Industry 4.0 is an approach that emphasizes bringing the principles and technologies of this industrial revolution to the agricultural sector. This perspective is important because it illustrates how modern agriculture can benefit from paradigms developed in other industries to become more efficient, sustainable and connected. Thus Agriculture 4.0 and Industry 4.0 are two interlinked concepts, both part of the digital revolution and the transition to extensive use of technology in different sectors of the economy. Both concepts are based on extensive automation and digitisation of processes, thus in Industry 4.0, automation and digital connectivity are used to improve efficiency in production processes, and in Agriculture 4.0, they are applied to optimise agricultural operations and manage resources intelligently, both Industry 4.0 and Agriculture 4.0 involve using IoT to connect devices, sensors and equipment into a smart network, in Industry 4.0, IoT is used for monitoring and controlling production equipment, and in Agriculture 4.0, it facilitates the collection of data from agricultural fields for informed decision-making. Both concepts take advantage of big data and predictive analytics to extract valuable insights from massive volumes of data, in Industry 4.0, these technologies help anticipate production needs and in Agriculture 4.0, big data and predictive analytics support real-time data-driven agricultural decision-making.

Artificial Intelligence plays a significant role in both contexts, either for optimizing production lines in industry or for providing smart solutions in agricultural crop management so in both cases, artificial intelligence is used to improve efficiency and provide customized solutions. Both Agriculture 4.0 and Industry 4.0 emphasise interoperability of systems by integrating diverse equipment and technologies to work together efficiently, in Industry 4.0 this translates into efficient use of energy and raw materials, and in Agriculture 4.0 the focus is on smart management of agricultural resources such as water and fertilisers.

Industry 4.0 promotes the automation of production processes and the systematic integration of devices and equipment in an intelligent network. In agriculture, this translates into the use of agricultural robots and autonomous machines that can perform tasks such as planting, harvesting and irrigation without direct human intervention.

The Internet of Things (IoT) and machine-to-machine (M2M) communication are key elements of Industry 4.0. In agriculture, this means using sensors and connected devices to monitor and manage farm resources and equipment in real time. For example, sensors can monitor soil conditions and send data to tractors to automatically adjust the amount of fertilizer applied.

Similar to Industry 4.0, Agriculture 4.0 relies on advanced data analysis to gain valuable insights. Data collected from various sources, such as sensors and drones, is processed using artificial intelligence and machine learning algorithms to make more informed crop and resource management decisions.

Industry 4.0 promotes flexibility in production and customization of products. In agriculture, this can translate into the ability to adapt agricultural practices to the specific conditions of each plot. Irrigation systems can be individually adjusted for each area of a farm to optimize water use according to needs.

The perspective of digital technologies within Agriculture 4.0 emphasizes the use and integration of advanced digital technologies to transform and improve agricultural processes. This approach is an essential focal point in the

development of Agriculture 4.0, bringing technology to the center of modern agriculture (table 1).

*Table 1*

**Perspective of digital technologies in Agriculture 4.0.**

| Digital technologies | Perspectives in Agriculture 4.0 |
|---|---|
| Sensors and smart devices: | Agriculture 4.0 relies on the extensive use of sensors and smart devices to collect data from the farming environment, sensors that can measure a variety of parameters such as soil moisture, air temperature, light levels and more to help understand the farming environment and make informed decisions. |
| The Internet of Things (IoT): | IoT is a key part of Agriculture 4.0, which involves connecting sensors and devices to the internet, allowing farmers to monitor and control these devices remotely. For example, a farmer can adjust the irrigation system from a smartphone using real-time data from IoT sensors. |
| Big Data Analysis: | Collecting data from multiple sources generates a vast amount of information called Big Data. Analysing this data is essential to extract valuable insights for agriculture, and data analysis algorithms can identify patterns, trends and anomalies that would be difficult to detect manually. |
| Automating agricultural processes: | Agricultural robots and autonomous machines can perform tasks such as harvesting, planting and tending plants without direct human intervention by increasing efficiency and reducing reliance on human labour. |
| Precise resource management: | Digital technologies allow precise management of agricultural resources such as water and fertilisers, and sensor data can be used to deliver specific doses according to exact crop requirements and stage of growth. |
| Informed decision-making: | With Big Data analytics, farmers can make more informed decisions, for example, they can plan the optimal time for planting and harvesting, identify problem areas in their fields, and adjust farming practices to maximise yield. |
| Continuous monitoring and control: | Farmers can receive real-time alerts when problems occur and take immediate action to solve them. |
| Sustainability and waste reduction: | Agriculture 4.0 can contribute to a more sustainable management of resources, reducing the waste of water, energy and natural resources by optimizing their use. |

Agriculture 4.0 extends the concept of Industry 4.0 also in food supply chain management. This involves using tracking and data recording technologies throughout the supply chain to improve food safety, reduce waste and ensure transparency. Agriculture 4.0 can also promote the concept of circular economy, where resources are used and reused efficiently. For example, agricultural waste can be turned into biogas or organic fertilizers, thus contributing to reducing waste and increasing sustainability. By integrating Industry 4.0 technologies, agriculture can optimize the consumption of resources such as water, energy and fertilizers, thereby reducing environmental impact and production costs.

The “beyond farm boundaries” perspective in Agriculture 4.0 is a holistic and broad approach that emphasizes that agricultural transformation is not limited to individual farms, but affects the entire food supply chain, from production to consumption. This perspective recognizes that Agriculture 4.0 has significant implications not only for farmers, but also for distribution, processing, packaging and consumption processes (table 2).

*Table 2*

**Agriculture 4.0 perspective on the food chain.**

| Stages in the food chain | Perspectives in Agriculture 4.0 |
|---|---|
| Integration with food production: | Agriculture 4.0 is not limited to agricultural production processes but encompasses the entire food industry, including the production of processed food, packaging, storage and distribution. Data and digital technologies are used to improve these processes, from supply chain optimization to inventory and logistics management. |
| Supply chain transparency: | by tracking and recording data throughout the process, which allows consumers to have access to detailed information about the origin of the food, the growing conditions and the treatment applied, contributing to increasing the trust and quality of the food products. |
| Food quality monitoring: | Sensors and IoT technology can be used to monitor the storage and transport conditions of food products, |

| | |
|---|---|
| | ensuring that they are delivered to consumers fresh and safe to eat. |
| Supply chain optimization: | Data from the entire supply chain can be analyzed to identify bottlenecks and optimize processes leading to a reduction in waste and costs while improving overall efficiency. |
| The consumer as an active party: | Agriculture 4.0 also involves consumers as an active part of the process through access to detailed information about the products they buy and can influence the demand for healthier and more sustainable food. |
| Rapid response to incidents: | Real-time data and data analysis can help quickly detect problems or incidents that may affect food safety allowing for immediate interventions to minimize risks. |
| Sustainability and reducing food waste: | Agriculture 4.0 has the potential to contribute to more sustainable agriculture and reduce food waste through more efficient supply chain management. |

By applying the principles and technologies of Industry 4.0 to the agricultural sector, Agriculture 4.0 can bring significant benefits, including increasing efficiency, reducing waste, improving the quality of agricultural products and contributing to a more sustainable agriculture that is more connected to modern market demands.

From this perspective, Agriculture 4.0 becomes a technological platform where data and automation are used to transform traditional agricultural practices into more efficient, sustainable and informed decision-making processes. This brings significant benefits to both farmers and society as a whole by increasing agricultural production and reducing environmental impact.

The perspective of informed decision-making in Agriculture 4.0 emphasizes the importance of decision-making based on accurate data and advanced analytics to optimize agricultural processes and increase efficiency, it emphasizes the transformation of data into valuable information and its use to make decisions that maximize the yield and sustainability of agricultural holdings.

This perspective "beyond the boundaries of agricultural holdings" emphasizes the importance of approaching the entire food supply chain to ensure a complete and sustainable transformation of the agricultural sector, thus by integrating and optimizing processes throughout the supply chain, Agriculture 4.0 contributes to increasing efficiency, improving food security and promoting a healthier and more sustainable diet for global society.

The ultimate goal under Agriculture 4.0 highlights that the main mission of this transformation is to create an agricultural system that is more sustainable, efficient and resilient to meet global challenges, focusing on solving major problems facing modern agriculture and achieving key objectives (figure 3). One of the main objectives of Agriculture 4.0 is to contribute to a more sustainable agriculture that involves reducing the impact on the environment, using natural resources more efficiently, such as water and soil, and reducing greenhouse gas emissions.

Agriculture 4.0 promotes sustainable agricultural practices that protect the environment and maintain biodiversity through the efficient use of resources such as water, energy and agricultural inputs (such as fertilizers).

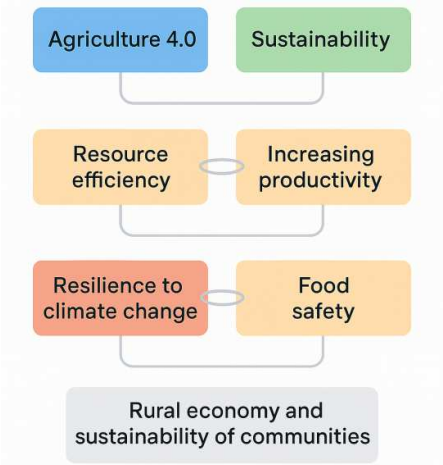


**Fig. 3.** The ultimate goal under Agriculture 4.0.

Another important goal is to increase agricultural productivity, through the use of digital technologies, Agriculture 4.0 can help increase crop yields and produce more abundant food, which is essential in the face of a growing world population.

Agriculture 4.0 aims to develop agricultural systems more resilient to climate change, data and digital technologies can help adapt to

changing weather conditions, manage the risks associated with extreme phenomena and maintain the stability of agricultural production by improving production and supply chain management, this can help reduce hunger and ensure that food reaches those who need it. Agriculture 4.0 can support rural economies by increasing agricultural production and developing economic opportunities.

Agriculture 4.0 connects farmers globally, enabling them to share knowledge, technologies and solutions that can help increase solidarity and understanding within the global agricultural community. The rapid development of Agriculture 4.0 brings undeniable benefits in terms of agricultural efficiency, sustainability, and productivity. However, in addition to these advantages, the introduction of advanced technologies generates new risks to the safety and health of agricultural workers. This reality requires a careful analysis of the potential hazards associated with autonomous equipment, the collection of sensitive data, and human-machine interaction in new digitized agricultural processes. Occupational risks in the context of Agriculture 4.0 are diverse and often underestimated in the literature. For example, the use of autonomous drones for crop monitoring involves risks of collision or electromagnetic interference, while autonomous tractors can pose significant hazards in the absence of human intervention protocols. At the same time, IoT sensors that monitor biological or environmental parameters can raise issues related to the protection of employees' personal data. Furthermore, wearable devices and smart interfaces can cause physical discomfort or musculoskeletal disorders if they are not ergonomic and adapted to users' needs.

*Table 3*

**Occupational risks associated with technologies in Agriculture 4.0.**

| Technology used | Possible risk to workers | Recommended preventive measure |
|---|---|---|
| **Autonomous drone** | Accidental impact, electromagnetic interference | Flying in delimited areas, operator certification, geofencing |
| **Autonomous tractor/ machinery** | Collisions, lack of human control | Emergency stop systems, LIDAR sensors, active signaling |
| **IoT devices** | RF exposure, reduced privacy | GDPR compliance, electromagnetic safety standards |
| **Agricultural robots** | Accidental entrapment of limbs | Human exclusion zones, proximity sensors |
| **Wearables/smart equipment** | Ergonomic discomfort, RSI (repetitive strain injuries) | Ergonomic design, specialized training |

In addition, the European legislative framework already provides clear guidelines on safety in the context of new technologies. Directive 2006/42/EC on technical equipment regulates the safe use of autonomous machines, while Regulation (EU) 2016/679 (GDPR) protects workers' data in the context of digitized agriculture, [13]. The OSHwiki platform (European Agency for Safety and Health at Work), [14] also proposes guidelines for adapting agricultural work to the new conditions imposed by digital transformations.

In this sense, integrating safety components into the design and implementation of Agriculture 4.0 systems is not only an ethical obligation but also a strategic opportunity for innovation. Technological solutions such as pesticide exposure detection sensors, real-time warning systems, augmented reality (AR) training, or predictive risk audits based on artificial intelligence can make a decisive contribution to reducing accidents and promoting a safe working environment adapted to technological change.

The research results reveal a strong correlation between the level of digital technology integration and agricultural sustainability indicators, according to the model presented in Figure 4. By simulating scenarios of progressive adoption of 4.0 technologies, it was demonstrated that: - The use of IoT (through soil and climate sensors) reduced water consumption by 18–25% on average, thanks to differentiated irrigation. - The integration of Big Data Analytics enabled the optimization of inputs (fertilizers and pesticides), leading to a 12–15% reduction in production costs.

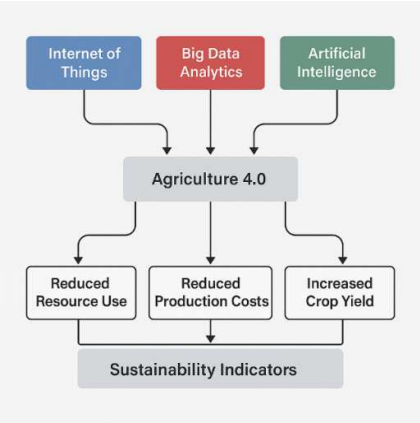


**Fig. 4.** Correlation between digital technologies in Agriculture 4.0 and sustainability indicators

AI algorithms used in sowing and harvesting decisions have increased average crop yields by 7–10%, depending on soil type and climate.

From an engineering perspective, the analysis identified the need to develop modular architectures for agricultural information systems, in which smart devices communicate in real time through standardized protocols (e.g., MQTT, LoRaWAN). Thus, interoperability between equipment and software platforms is essential for expanding the adoption of agriculture 4.0 in Romania. Furthermore, it was noted that the lack of national standards for agricultural data collection and processing is a major obstacle.

## 4. CONCLUSION

The study brought to the fore the prospects of Agriculture 4.0 for the development and sustainability of the agricultural system in Romania, thus highlighting the role that the use of digital technologies and data in agriculture is based on, contributing significantly in various areas that allow a more efficient management of agricultural resources, such as water, energy, and fertilizers, which can lead to a significant increase in the efficiency of agricultural operations, and IoT appears as a cornerstone in Agriculture 4. 0, connecting sensors and devices to the internet, for example, the ability to adjust irrigation systems in real time via smartphones based on data from IoT sensors. Collecting data from diverse sources gives rise to Big Data, a valuable resource in Agriculture 4.0, and advanced data analytics algorithms play a key role in extracting meaningful insights, identifying patterns, trends and anomalies that might be difficult to discern through manual efforts.

Digital technologies enable precise management of agricultural resources, including water and fertilizer, by harnessing sensor data, farmers can deliver specific doses tailored to the exact requirements and growth stages of crops, optimizing resource use.

The integration of sensors, IoT, Big Data analytics, automation and precise resource management in Agriculture 4.0 not only increases the efficiency and productivity of farming operations, but also fosters a more sustainable and environmentally conscious approach to agriculture, and in terms of the transformative impact of Agriculture 4.0 on different stages of the food chain, extending beyond traditional agricultural production, the insights presented reflect a paradigm shift towards a more integrated, transparent and consumer-centric approach to food production and distribution. The insights presented in Table 2 demonstrate that Agriculture 4.0 is not just a revolution in farming practices, but a holistic transformation of the entire food chain through increased transparency, consumer engagement and data-driven optimisation, such that Agriculture 4.0 has the potential to create a more resilient, sustainable and consumer-centric food ecosystem.

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## Agricultura 4.0: Noi Perspective pentru Sustenabilitatea Agriculturii în România

Agricultura se confruntă cu presiuni tot mai mari din cauza schimbărilor climatice, a lipsei resurselor, a schimbărilor demografice și a risipei alimentare. Pentru a face față acestor provocări, este esențială o abordare a gestionării întregii ferme, care implică colaborarea între părțile interesate, infrastructură și tehnologie. Agricultura 4.0 apare ca o soluție-cheie, care vizează îmbunătățirea sustenabilității prin integrarea unor tehnologii avansate precum cloud computing, IoT, AI, robotică, big data și analiza datelor. Aceste inovații permit luarea de decizii în cunoștință de cauză în diverse sectoare, sporind productivitatea și asigurând în același timp siguranța mediului și bunăstarea părților interesate. Implementarea unor procese eficiente la costuri reduse este esențială, necesitând eforturi coordonate din partea agricultorilor, agronomilor și factorilor de decizie politică. Agricultura 4.0 promovează sinergia între acești actori, îmbunătățind gestionarea exploatațiilor agricole și încurajând practicile durabile. Acest studiu își propune să exploreze rolul agriculturii 4.0 în România, evaluând capacitățile tehnologice, impactul și provocările acesteia în agricultura durabilă. Deși aceste progrese promit să revoluționeze sectorul, provocări precum securitatea datelor, accesibilitatea tehnologică și impactul social trebuie gestionate cu atenție pentru a asigura o transformare echilibrată și responsabilă.

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