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Technology and Big Data in Agriculture: an Analysis on Agriculture 4.0, Precision Farming, and the Role of SMEs in Driving Economic Growth

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RESEARCH ARTICLE

Abstract

This paper discusses the role of technology and big data in the agri-food industry. With the world population growing rapidly, there is a need to produce more food to feed everyone. Agriculture is changing rapidly, and technology is playing a crucial role in this change. The concept of Agriculture 4.0 seeks to optimize every factor to minimize inputs and maximize efficiency. Big data is being collected to improve management and farm management. Precision farming is being used to predict crop development phases and yields. The European Union is lagging behind the US and China in terms of innovation and market evaluation. Innovation drives economic growth, and it goes beyond invention. Small and medium-sized enterprises are playing an essential role in driving economic growth, particularly in the agri-food business. To improve resilience and production efficiency in the agri-food business, there is a need to boost SMEs' competitiveness. The European agri-food business is lagging in terms of digitalization, but there is a significant potential for growth. Finally, technology and big data are playing a crucial role in the agri-food industry, and there is a need to evaluate contextual elements to improve farmers' technology use.

Keywords: agriculture, technology, precision farming, digital transformation, economic growth, agri-food industry.

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INTRODUCTION

The biggest issue for civilization is feeding an expanding population. To change agriculture, creativity and technology are using drones, IoT sensors, precision farming, autonomous tractors, and satellite photography. Agriculture is swiftly adjusting to the tremendous technological developments altering the planet. As automated farming gear and IoT sensors that monitor crop health, soil moisture, and abrupt changes in agricultural circumstances become more available and user-friendly, traditional agriculture is dying. (Gagliardi et al. 2021)**.** Discovering more efficient agricultural farming methods is vital when the world population approaches 9 billion by 2050. Agriculture 4.0 seeks to analyze and optimize every factor—soil type, water, fertilizer, etc.—to minimize inputs and maximize efficiency. Data is collected in two main areas: management, which focuses on high-yield production with minimal inputs by gathering, analyzing, visualizing, modeling, and using IoT sensor data; and farm management, where technology and data help farmers make informed decisions. Agriculture 4.0's "Big Data" tendency is to

link everything and collect as many data (or "inputs") as possible. Precision farming uses crop modeling to predict crop development phases and yields (Bakthavatchalam et al. 2022). Farmers now discover plant breeder-friendly crops thanks to data analysis. Better food safety, crop nutrition, and lower production costs are essential for a successful, sustainable farm. Technology is a constantly changing market that requires ongoing adaptation, making it difficult to keep up. In response to customer demands, the agriculture sector is modernizing and simplifying farms. Farmers may blend technology and fieldwork by staying current on agriculture. Higher yields and better harvests are the goals of improved farming, simpler procedures, and lower expenses (Sharma et al. 2023).

Digital transformation has raised the potential of a more modern period when power and its acquisition and protection are reinterpreted. Economic disparities between the US, China, and Europe are well known. Only a few European companies are highly market-evaluated, thus they lag behind the US and China. Instead of welcoming competition from Uber and Airbnb, European Union states have reacted negatively to protect entrenched businesses (Buijvoets, 2020). In the long run, the move won't work since the industry must stay competitive and drive itself to improve. The internet is becoming a fully functioning infrastructure component of the global financial system; therefore, it will likely act as both the linking network and the foundation for further services and infrastructures. The European Union's (2016) lack of a compelling and well-defined vision of the internet and new economy delayed understanding of innovation's importance for economic growth. After careful consideration, the European Union accepts the above considerations and launches major digitalization efforts to retain global competitiveness and innovation. Innovation drives economic growth. It entails developing value-added concepts including high-quality goods, enhanced services, innovative production processes, and staff upgrades.

Innovation is complex and goes beyond invention. Complex adoption models are involved. It entails early participation in new technologies to build a solid basis. The idea that innovation boosts development productivity is not commonly accepted. However, non-innovative organizations usually beat those that adopt new technologies in revenue and employment growth. This implies that the innovation landscape is divided into two groups: organizations that aggressively embrace and implement innovation, and others that take a more cautious approach, believing they can continue operations using traditional techniques.

In the modern economy, small and medium enterprises have driven economic growth (Kaftan et al. 2023). Small and medium-sized companies (SMEs) have become attractive and innovative systems that directly contribute to key economic areas. These contributions boost progress and benefit society.

To improve resilience and production efficiency in the agri-food business, the best strategy has been to boost SMEs' competitiveness. Technology helps owners make decisions and improves output. To improve communication between firms that own and develop technology for farmers, particularly ICT distribution corporations.
Francisco (2024) reports that the European agri-food business is 13% digitalized, lower than other sectors. McKinsey (2022) reports 20% yearly growth in the European Agtech market. However, farm technology uptake remains disappointing. The AgTech market's needs are heavily influenced by contextual elements such farmer organization, value chain interactions, and climate and law. We can identify the main concepts that can improve farmers' technology use by evaluating these elements (David Fiocco et al., 2023).

Technology and big data in agri-food industry

The rapid pace of technology advances in recent years has made it hard to stay up. However, this innovation has led to foldable cellphones, self-driving cars and tractors, and intelligent homes that looked like science fiction a few years ago. Technological advances have brought several benefits to the internet. Our electronic gadgets allow us to stay in touch with people around the world thanks to quick technology. Instant messages, photographs, voice messages, and even our location may be sent to loved ones remotely. An app can promote water intake or send the user's heart rate to a doctor or trainer, while the wristwatch displays their last email.

Technology is unpredictable and adapts to consumer and industry needs. In the information age, efficient use of information gives companies a competitive edge instead of large investments. The capacity of small businesses to succeed in intensely competitive markets shows the relevance of technology in modern business. Industry 4.0 emerged due to technological advances and industrial growth. The need to rethink the manufacturing process led to autonomous and networked industrial production. Like smart devices, homes, and cities, factories and the manufacturing process are interconnected and can share data. These new technologies can reduce waste and improve efficiency, reliability, and environmental sustainability by improving accuracy.

Industrial digitalization is a planned investment to improve product quality and implement eco-friendly production methods. Industry 4.0 has enabled speed and precision, improving competitiveness and efficiency above traditional production processes, according to Abdelmajied et al. (2022). According to Corallo et al. (2018), the Milan School of Management Observatory found that Industry 4.0 concepts contributed to 25% increase in 2017. Figure 1 shows Industry 4.0's commercial value.

A broad network called the Internet of Things (IoT) connects various things to communicate data about their use and surroundings. Sensors on these gadgets provide their working condition. A shared platform for device communication is the Internet of Things (IoT). The platform safely captures sent data, integrates it, and does

analytics to retrieve relevant information.

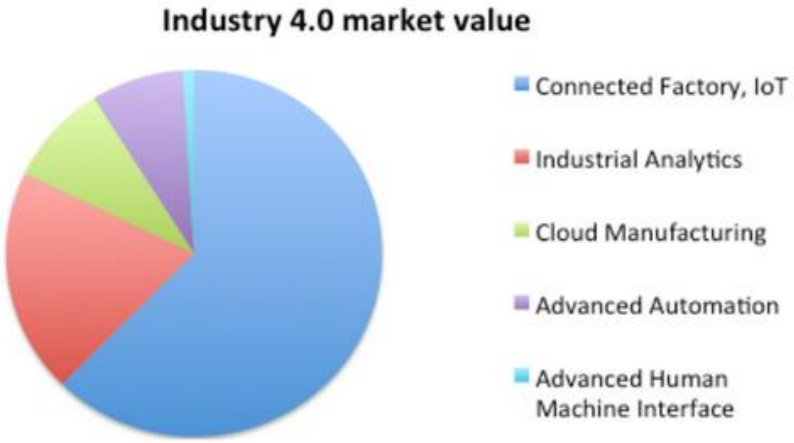

Figure 1. Breakdown of the market value attributed to Industry 4.0
Source: 2017 research of the industry 4.0 Observatory of the Milan Polytechnic

Alshehri et al. (2020) say the results are spread across connected devices to improve user experience, operational efficiency, and automation. The Internet of Things (IoT) connects every device to the internet at any time, place, and circumstance for any person, service, or business Figure 2.

Digital technologies like Big Data (BD) has changed the business. It has swiftly become a prominent subject with direct effects on various industries. Gartner (2012) defines big data as high-volume, high-velocity, and high-diversity information assets. These assets require efficient information processing systems to support and inform sophisticated decision-making systems.

Iqbal et al. (2019) said the fast growth of data is providing organizations and sectors with many challenges and opportunities. Local experts are already analyzing the new data for trends. BD's value resides in its ability to filter and choose the most relevant data (Thatcher, 2014). Next, distribute this data across the value chain to address the specific information. Enterprise information systems like Oracle and SAP hold structured data, including documents.

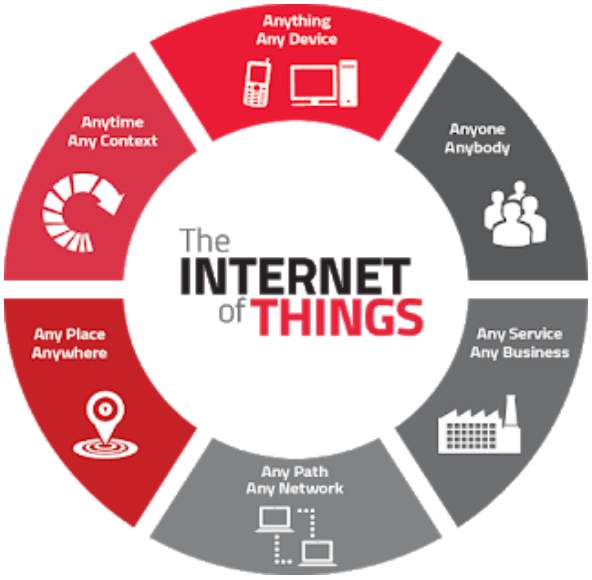

Figure 2. Internet of Things interlinks
Source: https://learninternetgovernance.blogspot.com/p/internet-of-things-iot.html

Unstructured data, such as emails, blogs, websites, social media pages, and instant messaging groups, makes up 85% of an organization's data (Iqbal et al., 2019). Despite organizations investing more in big data technology, their lack of expertise limits the process and the efficient use of the collected data. The Wikibon paper "Taming Big Data" addresses the large amount of digital data. Facebook stores, accesses, and analyzes about 30 petabytes of user data.

According to Kelly (2012), the U.S. Library of Congress possessed 235 terabytes of data in April 2011. Big data can help manage unstructured data regardless of sector or size. Data analytics helps firms identify performance patterns and trends, allowing them to correlate data sets to locate new revenue streams or issues (Bronson, 2016). Jin et al. (2021) report that the European Commission has increased funding for big data technologies to boost industrial competitiveness. Big data (BD) is rapidly evolving, therefore its numerous uses in education, healthcare, finance, industry, and agriculture must be acknowledged. Big Data (BD) may help with project creation, intelligent decision-making, cost reduction, and time efficiency. BD and advanced analytics can discover failure and issue reasons in near real time. BD can also forecast client buying trends and issue coupons. BD can also quickly rearrange a risk portfolio and discover fraud before it harms a firm.

MATERIALS AND METHODS

This study evaluates the possibility and efficacy of improving data collecting and use tactics in the agriculture and food industries to boost SMEs' competitiveness and resilience. This study seeks to identify key opportunities, problems, and methods for developing focused interventions to improve data-driven decision-making processes in small and medium-sized organizations (SMEs). The growing need to digitize and boost agriculture's competitiveness prompted this study. The agri-food business must improve resilience and production efficiency to meet population growth issues. Boosting SMEs' competitiveness has been the most effective way to achieve this. SMEs are vital to the agri-food business. An objective is to improve connectivity between firms that develop technology for farmers, particularly ICT distribution companies.

SMEs boost production efficiency and resilience in the agri-food industry. Digitization and competitiveness in agriculture are needed as the world population grows. Increasing SMEs is a proven way to achieve this aim. ICT distribution enterprises help farmers access technology, which is vital to the SME network. They are vital to the agri-food industry and SMEs' competitiveness. To achieve this, these firms must improve communication and devise strategies to promote new technology. Numerous studies have shown the importance of ICT in the agri-food business. According to the European Commission's (2021) assessment, digitalizing this industry requires a holistic approach. This study shows that the agri-food business needs more digital integration. To help ICT distribution companies embrace new technologies, support is essential. The UN Department of Economic and Social Affairs (2021) found that ICT may boost rural economies and societies.

This study seeks universal ICT best practices for diverse geographies, productive systems, and agricultural farms (Figure 3). Companies from numerous nations in the agrifood and ICT industries were surveyed about their present state, requirements, and prospects. The strategies these companies use to determine their customers and understand their needs have received much attention. A compendium of optimum methods was created after data analysis.

Our analysis included data from SMEs. Table 1 briefly describes them.

Figure 3. Geographical localization of selected SMEs

Source: Own determination

Table 1. The structure of the analyzed companies

SME	Country	Main activity
SME 1	Spain	Artificial Intelligence and Big Data
SME 2	Italy	Geographic Information Systems (GIS)
SME 3	Italy	Software solutions for traceability
SME 4	France	collaborative platform for producers
SME 5	Spain	Artificial Intelligence and Big Data
SME 6	Romania	Software solutions for agriculture
SME 7	France	Expert in climate modelling in greenhouse

Source: Own determination

RESULTS AND DISCUSSIONS

Since the dawn of civilization, agriculture and agricultural land have been crucial to all countries. The UN pledged to end world hunger by 2030 in 2015. To what degree are we approaching the goal? Answer: Not alike! Food insecurity affects 800 million people worldwide. Despite rising demand, food output is expected to rise 70% by 2050. According to Oliver Wynman's Agriculture 4.0 research, De Clercq (2018) says those who can see a world without poverty and food shortages are more likely to succeed. Humans have worked hard in the fields to produce goods for consumption. Humans evolved from manual work to mechanization as technology advanced. This move reduced the physical effort necessary for agricultural operations, allowing access to more food, especially nutritious food. Nutrient-dense diets have downsides, especially meat overconsumption. In developing nations, the lack of fresh and processed food has led to high rates of childhood obesity and chronic diseases including diabetes, hypertension, and cardiovascular disease. Many factors contribute to agriculture deterioration, including direct and indirect effects. Some major factors are:

- Overuse of fertilizers: Farmers often use fertilizers to address soil quality issues and promote crop output. However, this disrupts soil nutrient levels, causing an imbalance.
- Inadequate crop rotation: Farmers choose cereal-based vigorous rotations over balanced ones due to budgetary limitations and economic concerns.
- Deforestation and overcutting refer to the intentional destruction of natural forests in rural areas for timber, fuel, and other wood products. Due to intensive tree cutting, water and wind erosion degrade soil, making it unsuitable for food crops.

Agriculture digitization is intended to address major sustainability issues. Social discourses will shape political, legal, and economic institutions. Social discourses reflect agreed meanings and perceptions. Martens and Zscheischler (2022) say "truth regimes" duplicate power dynamics and generate policy. In view of exponential population growth and rising global food demand, Amiri-Zarandi, M. suggested increasing agricultural productivity. Smart farming collects data from wireless sensor networks, monitoring cameras, and cellphones. These issues hinder service delivery, data integration, and data exchange. The platform technique, suggested by Amiri-Zarandi et al. (2022), guides the creation of effective, reliable, and robust smart agricultural systems.

Precision agriculture (PA) uses a variety of technologies to improve agricultural management and control. PA requires a thorough understanding of ICT systems and the use of GPS navigation, sensors, drones, robotics, and autonomous vehicles Figure 4. PA began in the early 1990s with tractor GPS guidance. John Deere pioneered this technology by using GPS satellite location and GPS-enabled tractor controls to autonomously explore and follow field coordinates. Human steering errors and field overlap decreased, improving seed, fertilizer, water, fuel, and time economy.

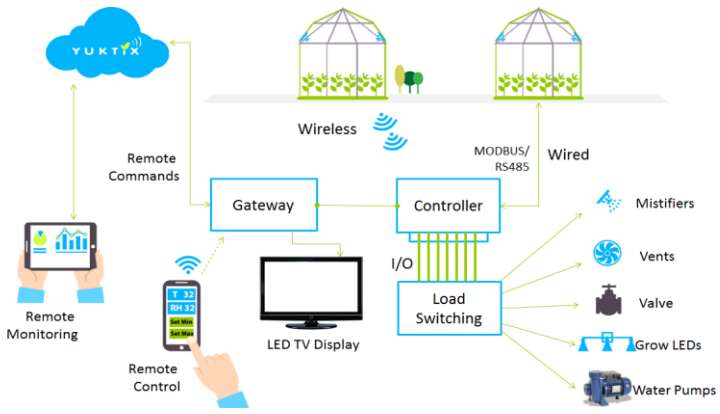

Figure 4. Smart Farming Grid
Source: http://www.yuktix.com/agriculture/

Create and deploy a distinctive European Digital Model is a huge challenge. However, with digital technology so pervasive in society and our personal lives, we must commit the government to US and Chinese economic and national interests. Remember that Europe has a long way to go. Though Europe is not at the forefront of all digital innovation and products, and there are significant differences within Europe, technological competence is generally high, many citizens are highly skilled and educated, and we have functioning EU and national institutions for the collective action needed to succeed with a European digital approach.

ICT adoption

In conclusion, the agriculture business is receptive to ICT solutions to improve operations and efficiency. These solutions must be adapted to the agriculture industry to be effective. Many companies provide solutions, making it difficult for farmers and agri-food business owners to choose the best one. Managers may also be unaware that ICT solutions exist to solve their problems, as it follows from the study of Ayim et al. (2022). Many agricultural enterprises want to engage a digitization specialist, but the cost might be a hurdle. To address these challenges, research and development must continue to create agricultural sector-specific solutions that are user-friendly, affordable, and accessible to farmers and agri-food business owners.

The global economy relies on the agriculture sector, and technology is increasingly critical (Nugroho and Lakner, 2022). Technology like precision agriculture, animal farming, and forestry is helping farmers and agribusinesses boost yields, efficiency, and profitability. Sensors, drones, and other technology may help farmers monitor crop and livestock health, optimize resource usage, and make better decisions. Blockchain and digital marketplaces are also helping farmers and agribusinesses interact with customers and increase food supply chain transparency and traceability.

Adopting ICT solutions in agriculture has drawbacks. The expense of technology is a major issue for farmers and agribusinesses who cannot afford pricey equipment and software, aspect also identified by Khan et al. (2021). Some farmers and agri-business owners lack technical expertise and abilities, making it hard for them to understand and apply the technology. More research and development is needed to build agricultural sector-specific, user-friendly, inexpensive, and accessible solutions for farmers and agri-businesses. Finally, the agricultural business sector is receptive to ICT solutions, but they require customized, inexpensive, and accessible solutions for all farmers and agri-businesses. More research and development is needed to build agricultural sector-specific, user-friendly, inexpensive, and accessible solutions for farmers and agri-businesses.

Agrifood ICT solutions

ICT businesses may be giving solutions to agrifood enterprises, but their efficacy in meeting agricultural demands is unclear. Farmers and agri-food industry owners may struggle to choose the best ICT solution among the many vendors (Khan et. al. 2021). Managers may also be unaware that ICT solutions exist to solve their problems. Thus, ICT companies must continue to research and develop agricultural solutions that are user-friendly, affordable, and accessible to farmers and agri-food business owners. This will guarantee that the solutions meet agricultural demands and boost their chances of adoption.

Besides the above issues, the ICT business has typically served major enterprises. These systems may be customized for each customer, but they are expensive because of ICT wages. Small and medium-sized agri-food firms may struggle to afford these solutions. Recently, ICT corporations have shown more interest in agri-food solutions (Pellegrini et al. 2023). Several initiatives subsidize ICT and digitization solutions for agri-food industries, which may explain this. These incentives certainly made these solutions more inexpensive and accessible for these firms. Increased knowledge of digitization in agriculture may possibly have contributed to this desire.

ICT businesses provide solutions to agri-food enterprises, but their high pricing and concentration on large corporations might make them unaffordable for small and medium-sized companies. ICT businesses' increased involvement in the agri-food sector, financing programs, and digitalization awareness have likely made these solutions more accessible and inexpensive for these enterprises.

Agrifood ICT firm attributes

An ICT business must have numerous traits to persuade agrifood clients to choose ICT solutions. First, the firm must have a track record of successful initiatives, preferably with agrifood enterprises. This showcases the company's competence. The organization should also offer demo solutions or software to potential clients so they can examine their capabilities and make an informed selection. The organization should also be empathetic and prepared to tailor its solutions to the agrifood industry and particular clients.

As demonstrated by Bustamante, M. (2023) employees with agrifood knowledge and a passion for developing solutions can help an ICT business convince agrifood clients to use their solutions. This helps the organization understand the sector's particular issues and demands and offer customized solutions. Finally, agri-food clients need a lexicon that matches their knowledge. ICT companies must communicate well with clients and explain solution characteristics and benefits in a way they can grasp. An ICT company can persuade an agrifood client to

use their solutions by showing a track record of success, providing demo solutions, being open to empathy, having employees with relevant experience, and having an appropriate communication style.

Agrifood ICT firms' differentiators and value proposition

ICT firms must have specific traits to be considered a useful partner by agri-food enterprises when adopting ICT solutions. These include having a track record of successful projects, being able to provide demo solutions or software, being open to understanding and adapting to the agri-food sector's needs, having employees with relevant industry experience, and communicating effectively with potential clients.

A relationship between ICT and agri-food enterprises should be mutually beneficial, yet the profit is often not shared (Kumar et al. 2020). Strategic planning, big data access and interpretation, labor replacement options, enhanced promotion and sales tactics, and cost management in transportation, storage, and logistics are common value propositions for agri-food enterprises. Agri-food enterprises must additionally examine technological access, installation and maintenance costs, commercial value, and long-term ROI.

Agriculture technology supply-demand alignment

Overall, agricultural supply and technological demand are being adjusted. Agri-food and ICT firms have collaborated. For instance, the AgroTransilvania Cluster and Transilvania IT Cluster collaborate on agricultural solutions. However, agricultural supply and technology demand can be better aligned. Both parties must continue to collaborate to identify and solve agriculture sector needs and difficulties and create new solutions to boost efficiency and production. Increasing communication, coordination, and cooperation amongst agricultural players including agri-food firms, ICT companies, research institutions, and government agencies can achieve this.

CONCLUSIONS

The rising worldwide population has led to a surge in food consumption, necessitating the modernization of agriculture, with technology playing a crucial role. Agriculture 4.0 and precision farming are essential for enhancing efficiency and sustainability. These technologies optimize agricultural practices by leveraging big data and IoT to boost productivity while minimizing resource use. Agricultural practitioners employ technology to enhance decision-making, optimize crop nutrition, ensure food safety, and reduce production expenses. Although there have been advancements in agricultural technology, the European Union falls behind the United States and China in terms of innovation and market dynamics. The existence of this gap highlights the need for the EU to strengthen agri-food innovation and digitalization. SMEs in this industry need to enhance their competitiveness in order to stimulate economic growth and foster innovation. The utilization of advanced technology and the adoption of digitalization have the potential to enhance both growth and production efficiency. In order to enhance the agri-food business and maintain global competitiveness, it is imperative for the European Union (EU) to conduct an assessment of climate, regulatory frameworks, and value chain connections. The adoption of this strategic emphasis will enhance the integration of agricultural technology, so facilitating more informed decision-making and the utilization of resources. The EU can enhance the resilience and efficiency of the agri-food industry by promoting digital transformation and fostering innovation among small and medium-sized enterprises (SMEs), while also meeting the sustainable demands of a growing population.

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Conflicts of Interest

The authors declare that they do not have any conflict of interest.

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