



Agriculture Digital Transformation: Opportunities and Challenges

Abdeslam kellou *

Abdelhamid Ben Badis University of
Mostaganem, Research Laboratory
Macroeconomic Dynamics and Structural
Changes, (algeria)

Abdeslam.kellou.etu@univ-mosta.dz

Mustapha benamer

Abdelhamid Ben Badis University of
Mostaganem, Research Laboratory
Macroeconomic Dynamics and Structural
Changes, (algeria)

mustapha.benamer@univ-mosta.dz

Abstract

This research paper aims to address the opportunities and challenges facing the agricultural digital transformation. We divided our research into three axes using the descriptive analytical approach, through which we addressed the nature of agricultural digital technologies, their areas of application, their most important tools and requirements, and the most important opportunities and challenges facing us during the agricultural digital transformation. The study objectives concluded that modern technologies provide many opportunities to increase agricultural productivity and improve the efficiency of operations through precision agriculture, geographic information systems, and other applications. However, achieving these benefits depends on addressing challenges such as the lack of digital infrastructure in rural areas and the limited digital knowledge and skills of farmers.

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1. Introduction

With rapid technological advancements, the world is witnessing a digital transformation across sectors, including agriculture. New digital technologies, such as smart agriculture, offer applications that rely on big data. Digital technologies and the Internet of Things offer great potential to enhance productivity, efficiency and sustainability in the agricultural sector. However, digital transformation in agriculture faces several key challenges that may hinder its widespread adoption. One of the key challenges is the need for significant investment in digital infrastructure. Developing the necessary connectivity, sensor networks and data management systems to enable the deployment of advanced digital technologies in agricultural environments requires significant capital investment. Another critical challenge is ensuring the practicality and seamless integration of digital solutions at the farm and field levels. Digital technologies and applications need to be tailored to the specific needs, operating environments and constraints of different agricultural contexts to be of real value and usability to farmers. Furthermore, the availability of the necessary skills, knowledge and digital literacy among farmers and agricultural workers is essential to effectively leverage and extract value from these new technologies. Addressing the digital skills gap is a critical factor for successful digital transformation in agriculture. Furthermore, considerations of data ownership, privacy, and trust can create barriers to adoption, requiring careful development of data governance frameworks that build trust among farmers and other stakeholders. Finally, the regulatory environment, including policies and standards related to digital technologies in agriculture, can enable or hinder the pace of digital transformation, underscoring the need for a supportive and enabling policy environment. Addressing these multifaceted challenges through coordinated efforts that include diverse stakeholders, such as policymakers, technology providers, and farming communities, will be critical to realizing the full potential of digital transformation in the agricultural sector.

Agricultural digital transformation supports agricultural productivity and improves operational efficiency through precision agriculture applications and geographic information systems, enabling farmers to make better decisions about resource use. Second, digital solutions help enhance the environmental sustainability of agricultural practices by rationalizing the Monitoring and managing environmental risks and the use of natural resources. Digital technologies also improve the connectivity of agricultural supply chains and enhance transparency and efficiency, including product traceability and food Safety. Agricultural digital transformation also contributes to the economic and social development of rural areas. Areas by increasing farmers' incomes and creating new jobs. Accordingly, digital transformation in this sector is a key focus of agricultural Development policies at the national and international levels.

By addressing these opportunities and challenges holistically, the agricultural sector can harness the power of digital technologies to enhance productivity, efficiency, sustainability,

and overall competitiveness, ultimately ensuring a more resilient and future-ready food system.

By undertaking a comprehensive examination of these key aspects, the study aims to provide a holistic understanding of the opportunities and challenges facing the digital transformation of agriculture. The insights generated can inform the development of strategies, policies, and interventions to unlock the full potential of digital technologies in this vital sector, ultimately contributing to more productive, efficient, and sustainable agricultural practices.

The problem of the study:

Through what you may present to us, the features of the problem of our research emerge, which can be formulated as follows:

What are the opportunities and challenges of agricultural digital transformation?

Agricultural digital transformation supports economic and social development in rural areas, but this is hampered by the digital environment in agricultural areas, whether infrastructure or knowledge and expertise.

The importance of the study:

The importance of our study revolves around the opportunities and challenges facing agricultural digital transformation for several key aspects, including enhancing national food security and knowing the basic factors that determine the path of digital transformation. Help in developing appropriate solutions to enhance Harnessing the potential of digital technology and the contribution of digital transformation to improving agricultural production in increasing productivity and agricultural resources and overcoming challenges will help connect farmers to more efficient and competitive markets locally and globally and analyzing challenges will help design More effective government strategies and interventions to promote digital transformation in agriculture.

Overall, knowing and understanding the key factors associated with agricultural digital transformation will provide important insights for policymakers and practitioners to make the most of the potential of digitalization in improving food security and rural development.

Objectives of the study: Through our study, we seek to identify and analyze the most prominent opportunities the challenges we face in the process of agricultural digital transformation and identifying the necessary modern technological infrastructure support agricultural digital transformation.

Achieving these goals will help provide a comprehensive view of the reality and challenges of agricultural digital transformation and direct decision-makers' efforts towards effective planning and implementation of this transformation.

Research Methodology: The research is based on the descriptive approach to digital technologies, agricultural digital transformation, and their areas of use, and on the analytical approach to present and analyze the reality of the agricultural sector and its challenges.

To address this issue, we will address the following axes:

The first axis: the nature of agricultural digital transformation.

Second axis: Requirements and Techniques for Achieving Agricultural Digital Transformation

Third axis: Opportunities and Challenges of Digital Transformation in Agriculture.

2. The meaning Digital Transformation in Agriculture

Agriculture has witnessed a series of developments in the past, from traditional agriculture to modern agriculture, which we will discuss in detail.

2.1 Definition of agricultural digital transformation and smart agriculture

➤ Definition of agricultural digital transformation:

Given the inherent complexity and context-specific nature of this process, there is no single, universally accepted definition of digital transformation in agriculture. Instead, it must be understood within the unique circumstances and constraints of different agricultural systems and communities. (Del Río, G.; González Fernández, & Uruburu Colsa, Á, 2021, p. 280)

Digital transformation is the value creation opportunity that comes from the use of digital technologies. Analog Signal Conversion Digital transformation involves converting traditional, physical or “analog” information and processes into a digital format, allowing them to be stored, processed and disseminated in a more efficient and scalable manner, opening up new avenues for value creation across different domains, including economic and social domains. (Ritter & Pedersen, 2020, p. 183)

Digital transformation is not confined to specific sectors or industries with clear boundaries. Rather, it is a pervasive process driven by the convergence of digital innovations across the economy and society. These convergent innovations are transforming entire industries and the various actors involved.

The common thread among the different definitions of digital transformation is the acknowledgment of the profound transformative potential of digital technologies. These technologies are not just tools for incremental change, but have the capacity to drive systemic transformation.

Furthermore, digital transformation is increasingly being recognized as a means to address sustainability challenges. There are growing indications that a sustainability-focused approach will be central to the continued development of the digital age. The interplay between digital innovation, value creation, and sustainability is emerging as a critical dynamic shaping the future. (Schnebelin, Labarthe, & Touzard, 2021, p. 600)

Digital transformation is a process of change enabled by digital technologies. These technologies have the power to drive radical innovation, with the potential to positively transform social units ranging from individuals to organizations, networks, communities, and even society as a whole. Digital transformation creates new opportunities to generate value in transformative ways.

However, it's important to recognize that the process of digitization also introduces uncertainty and potential adverse effects that must be accounted for. The broad impacts of digital transformation must be carefully considered.

In the context of agriculture specifically, digital transformation refers to the application of data-rich software, hardware, and services. This enables increased productivity and efficiency, while simultaneously reducing costs, labor requirements, and environmental impacts. The result is the emergence of new forms of technology-driven, data-centric agriculture, often described as digital agriculture, smart agriculture, or Agriculture 4.0. (Shepherd, Turner, Small, & Wheeler, 2020, p. 5084)

➤ *The concept of digital agriculture*

Digital agriculture has emerged with the advent of the use of digital technologies and advanced technology in all aspects of the agricultural sector, from farm management to crop and livestock production.

It has been defined as an integrated system that uses advanced and modern technologies to empower farmers and other agents in the agricultural value chain. The primary goal is to Increase agricultural production and provide food more efficiently. Modern digital technologies rely on digitizing various aspects of the agricultural value chain, including the provision of basic products information services to farmers. These services help farmers use modern technologies to increase productivity and profitability. For example, provide real-time information on planting dates, suitable crop varieties, weather data, and market price forecasts. Digital agriculture enables the management of agricultural operations in a smarter and more sustainable way.

Digital agriculture is increasingly prevalent in developed countries, with great benefits for farmers. Based on accurate measurements and analyses of various agricultural data, farmers are able to make more accurate and Making appropriate decisions about the use of agricultural production components such as pesticides and fertilizers. And irrigation water.

Once the farmer has identified his optimal business plan, he can implement it with high accuracy using advanced digital technologies, such as robots and modern machines. Agricultural operations are thus more efficient and effective. The digital agriculture system collects data frequently and reliably, combining it with external information such as the weather, enabling the farmer to make more accurate and timely decisions.

Thus, digital agriculture increases crop production and improves the quality of agricultural products, and contributes to the sustainability of natural resources through the optimal use of natural resources, which leads to enhancing the competitiveness of farmers in local and international markets. (Ashraf Abdel-Elahi, 2021, p. 117)

2.2 Effects of the shift to digital agriculture

➤ Digitalization and the use of digital data have profoundly transformed the entire agricultural and food production system. This transformation is now entering a new phase, driven by the rapid development of information technologies such as the Internet of Things (IoT), cloud computing, big data analytics, and artificial intelligence (AI). As a result, digital data has emerged as a new and critical business resource, with algorithms proliferating and shaping activities across the agricultural value chain. The increasing digital connectivity of agricultural production processes and the overall value chain, often referred to as the “Internet of Things,” is leading to fundamental changes in how work is organized and managed within the agri-food sector conditions, which are shaping the next "technological revolution" in agriculture. (erdouw, Tekinerdogan, Beulens, & Wolfert, 2021, p. 11)

➤ The next stage of digital transformation in agriculture brings both new opportunities and consequences. These social and technological changes in digital and smart agriculture offer considerable benefits and potential. Digitalization has advanced the agricultural value chain, enabling greater efficiency, improved decision-making through timely information, and increased productivity and profitability.

This transformation also promotes more sustainable and environmentally-oriented agricultural practices. Digital technologies allow for more precise application of inputs like nutrients and pesticides, tailored to specific plant, soil, and environmental conditions.

This reduces waste, lowers emissions, and improves resource efficiency, with positive impacts on climate change, biodiversity, and animal welfare. Additionally, digitalization increases transparency and traceability in food production, providing consumers with better information. It also opens new possibilities for designing and implementing agricultural policies, as digital technologies enhance monitoring and data-driven decision-making.

Overall, the digitalization of agriculture presents opportunities to help address pressing global challenges, such as climate change, land degradation, and food security for a growing population. While not without risks, the transformative potential of these technologies is significant. (Balafoutis, et al., 2017, p. 15)

➤ Technological advancements have certainly driven significant gains in agricultural yields and efficiency. However, these advances have also led to concerning environmental consequences. The digital transformation underway in agriculture has enabled notable socio-technological developments. Yet, this process also introduces new risks that warrant careful consideration. A key concern is the potential for growing inequality as access to emerging agricultural technologies becomes uneven. Producers with greater financial resources will be better positioned to adopt these innovations, shifting the balance of power and concentration towards large global agricultural suppliers and technology companies.

This unequal access to digital agriculture technologies could exacerbate existing disparities among producers. It may alter the competitive landscape in ways that benefit some players while disadvantaging others. The risk is that the benefits of agricultural digitalization may not be evenly distributed, potentially widening socioeconomic gaps within the sector. (Singh, 2000, p. 99)

2. Key trends in agricultural digital transformation:

Digital transformation in agriculture is a blueprint for sustainable agricultural development at both national and international levels. Here is an overview of the main trends in agricultural digital transformation.

Table 1. Key Aspects of Digital Transformation in Agriculture

Exploiting digital agricultural aerial information	With the help of modern digital meteorological technology, we can conduct fieldwork based on the analysis of data related to weather, soil temperature and moisture, and wind speed, etc., and reduce agricultural production costs.
Smart Agriculture	Management decision-making systems and the use of technical techniques and tools aimed at managing productivity parameters that affect plant growth are useful to us in crops, and digital transformation is very precise in this direction whether in crop planning and mapping or calculating soil fertility, fertilization and applying plant protection tools.
Smart animal husbandry	By utilizing these new digital devices, farmers and producers can gain deeper insights into their livestock's feeding patterns, physiological conditions, and reproductive cycles. This enhanced visibility allows for more proactive and individualized approaches to animal care, health management, and nutritional optimization.
Big Data Analysis	Agricultural big data analysis allows processing of large amount of different information to make appropriate decisions to serve agriculture.
Agricultural Management	By integrating these diverse data sources and analytical capabilities, producers can gain holistic visibility and management of their agricultural operations. Satellite imagery allows for remote monitoring of crop and livestock status across expansive areas. Video analysis and sensor data provide real-time insights into animal behavior, health metrics, and environmental conditions. Weather station inputs further enable proactive planning and risk mitigation. This integrated digital management system empowers producers to make more informed, data-driven decisions to optimize the productivity and sustainability of their agricultural enterprises. The ability to constantly monitor, analyze, and respond to a wide range of operational factors represents a significant advancement in modern farm management practices.
Global Tracking Systems for Agricultural Equipment and Machinery (Agricultural Tracking)	By equipping agricultural machinery with GPS tracking devices and integrated sensors, farmers can gain unprecedented visibility into the movements, activities, and productivity of their equipment. Data collected from these global tracking systems provides insights into factors such as vehicle routes, operating hours, fuel consumption, and maintenance needs. This comprehensive monitoring capability enables farmers to optimize the utilization of their machinery, ensure proper maintenance, and enhance the overall efficiency of their agricultural operations. Insights derived from global tracking systems enable data-driven decision-making to improve asset management, reduce operating costs, and enhance the productivity of agricultural enterprises.
Relying on drone technology	Drones equipped with high-resolution cameras, multispectral sensors, and other specialized payloads allow farmers to conduct comprehensive aerial surveys of their fields. This aerial perspective enables early detection of crop health issues, identification of weed infestations, and optimization of irrigation and fertilization strategies. The real-time data and imagery gathered by drones empower farmers to make more informed, data-driven decisions to improve yields and resource efficiency.

Source: (Kudratova and Turdibaevna, 2024, page 03)

3. Requirements and areas of applications of smart agriculture

To achieve agricultural digital transformation, there are a set of basic requirements that must be met, the most important of which are:

3.1 Techniques used in smart agriculture

Smart agriculture relies on modern technologies and their uses such as the Internet of Things, mobile phones, satellite imagery, digital security, remote sensors, drones, artificial intelligence, agricultural robots, self-driving tractors, automatic grain unloading, and data analysis and processing systems, and the following are the most prominent manifestations of this investment:

3.1.1 Modern IT farming techniques:

- **Relying on the Internet of Things:** The Internet of Things is one of the most important technologies used in smart agriculture. The Internet of Things is simply the process of connecting any device to another via the Internet, from mobile phones to home appliances and machines used in agricultural fields that can be operated, controlled, and send and receive data via the Internet. These devices collect and process data frequently, enabling farmers to respond quickly to emerging issues and changes in surrounding conditions. This cycle begins with observation, diagnosis, and then decision-making.
- **Mobile adoption:** Mobile phones are at the forefront of transformative digital technologies for agriculture, representing the fastest adoption rates of any technology invented in the past century. As of 2019, an estimated 5.2 billion people, two-thirds of the world's population, were active mobile phone users. Farmers also rely heavily on mobile phones to receive market information and monitor weather forecasts.
- **Satellite images:** Recently, the use of satellites in agriculture has become common, as they are used to monitor crops remotely, and this saves a great deal of money and time, and this technology can be combined with soil, water and crop models, so whenever there is a danger or lack of resources, the farmer can get a notification, and one of the most important roles of satellites is weather forecasting and this enables the farmer to determine the dates of sowing seeds or postpone the harvest and others.
- **Digital Security:** With this technology, it will serve as a record in which the food journey, from farm to table, is recorded by the consumer, which works to reduce damage and waste, and identify areas of greatest need.
- **Remote sensors:** Remote sensors have become available and easy to use in the agricultural field, and their cost is low and affordable for farmers, and agricultural equipment is equipped with sensors, and this enables farmers to read everything about plant health and water needs, and irrigation is the latest field of use of these devices where sensors measure water needs, help improve water use and avoid crop loss through agricultural pests.

3.1.2 Modern equipment farming techniques

- **The use of drones:** It is one of the techniques adopted in smart agriculture in order to monitor and evaluate crops, photograph agricultural lands, draw maps, measure air components, in addition to spraying crops with pesticides quickly and safely, and sending

data immediately to software that analyzes them and directs farmers to implement the best procedures, and drones are used to identify affected plants until the necessary remedial measures are taken, and farmers can spray diseased crops By drones with materials to bring them back to life, where they can spray fertilizer 40 to 60 times faster than doing it by hand.

➤ **Reliance on robots in smart agriculture:** Smart agriculture has become dependent on robots in many cases, so that it is expected in the future that it will invade fields and farms, and farmers will turn into programmers, data analysis experts and robot developers, and what encouraged reliance on it is its ability to work around the clock, as it collects a huge amount of data, and carries out a large number of tasks, which opens up prospects for increasing production and improving its quality while reducing the use of pesticides and fertilizers in large quantities.

➤ **Self-driving tractors:** This technology works without the need for labor, self-driving tractors do all agricultural work from plowing the land, to harvesting, and there are no public safety and security concerns in this modern agricultural technology because there are no other people or vehicles that can collide with it.

➤ **Electric drive systems:** It is a new step towards the development of agricultural technology, by inventing electric drive systems that are based on making agricultural vehicles, spray machines, and other vehicles generate electrical energy to operate utilities and accessories.

➤ **Automatic grain unloading:** This technology is based on mobility systems that automatically guide grain carts along with harvesters in order to improve cart packaging, and high harvesting efficiency can be achieved through improved unloading. (Dr. Nadia et al.)

3.2 Requirements for achieving digital transformation

Based on the multiplicity of concepts of digital transformation, it can be said that digital transformation requires (Nabila, 2021, page 419)

Encouraging leadership and administrative support for transformation efforts, through governments' interest in administrative practices related to innovation and technology, providing qualified human capital, financial resources and necessary legislation, reviewing traditional structures, adopting more flexible organizational models that allow adaptation to rapid changes and continuous innovation, and forming effective and multidisciplinary work teams.

➤ The need to monitor and adapt the digital transformation plan periodically, rather than considering it a one-time process. This is vital to ensure the long-term success of digital efforts.

➤ It is necessary to review and develop existing organizational structures, and these structures must be simplified and made more flexible, which increases the organization's ability to keep pace with technological changes and create a competitive advantage.

➤ The concerned authorities should implement training and self-development programs directed to all youth groups by investing in developing the capabilities of young people in a comprehensive manner, so that they will be able to develop themselves and achieve their full potential, which will positively reflect on the progress and prosperity of society. To keep pace with the rapid developments in information technology, it is necessary to provide the

necessary basic infrastructure, the renewal and modernization of the information technology infrastructure will contribute to raising the level of digital services provided, and enhancing performance efficiency in various sectors.

The availability of a set of capabilities, skills and personal traits among leaders and all members of society. The availability of these skills and personal traits will achieve the goals of digital transformation and success in society.

➤ Spreading digital culture, which increases the spread of the use of technology and the Internet and transforms the culture of technology and digitization. from an optional topic to a basic competitive advantage owned by leading societies and organizations. This, in turn, contributes to accelerating and promoting the widespread adoption of modern technologies.

3.3 Prerequisites for agricultural digital transformation

To ensure the success of the digital transformation of agriculture, there are a set of prerequisites required.

First: infrastructure and connectivity must be ready, such as mobile network subscriptions, good network coverage, Internet access, and adequate electricity supply. The adoption of digital technologies in rural areas is not without challenges. Rural populations are declining worldwide, limiting their educational and employment opportunities. In addition, the necessary ICT infrastructure is often absent, especially in communities. Remote rural and with large indigenous populations.

Second: Digital technology must be affordable, and the costs of building this digital infrastructure pose significant challenges in rural areas, especially in developing countries where poverty rates are high. Therefore, the successful adoption of digital technologies in rural areas requires addressing these challenges related to infrastructure, poverty, and providing opportunities for rural people.(Trendov. M, Samuel, and Meng, 2019, page 03)

Third: Farmers and agricultural workers need adequate education and knowledge of ICT, educational attainment, e-literacy and employment in rural areas. Education is dual in nature, with illiteracy rates remaining high in developing countries and, although gradually declining among young people, still a barrier, partly due to the lack of attention paid to digital transformation in the education system, which would reduce school dropout rates and improve the quality of education. On the other hand, illiteracy poses a challenge in providing the skills needed to interact with digital technology.

Fourth: there must be strong institutional support that provides the necessary guidance and training to effectively use digital technologies IT infrastructure and networks in rural areas There are still significant digital divides that exist within and between countries Not all populations are able to access or benefit from these technologies to the same degree. Disparities in the spread of digital infrastructure and Internet access between different regions, especially between urban and rural, do not It remains a challenge. The digital divides between developed and developing countries remain wide, so despite tremendous advances in ICTs,

there is a continuing need to bridge digital divides and ensure equitable and universal access to these technological advances for the entire population.

Fifth: Having the right digital skills and expertise among the workforce in the sector, along with a supportive regulatory framework, is essential for the success of digital transformation in this vital area. Policies and programs to enable digital agriculture Government policies and procedures are essential for digital transformation, as they provide an enabling environment for competitive digital markets and e-services. There is a growing trend towards digitizing governments (e-government) to deliver e-services, especially in areas such as health, education, and the environment. However, designing and managing a digital government program requires a high level of administrative capacity, and as a result, some countries have had limited success in this regard. (Fakhoury, 2018)

4. Opportunities and challenges of agricultural digital transformation

4.1 Opportunities in agricultural digital transformation

- Digital agriculture is a path to transformation. By analyzing data, sensors, and satellite imagery, professionals can empower farmers to gain real-time insights into critical factors such as soil health, weather conditions, and crop performance. This wealth of information becomes a powerful tool for farmers, enabling them to make informed decisions, optimize resource use, and ultimately boost productivity.
- Electronic marketplaces and supply chain management are undergoing a paradigm transformation through digital platforms. Specialists can devise solutions that connect farmers directly with consumers, eliminate intermediaries and streamline the supply chain. These digital marketplaces not only guarantee fair prices for farmers, but also make high-quality products affordable for consumers.
- The development of easy-to-use farm management software is another noteworthy opportunity. Specialists can develop solutions that help farmers plan, monitor and analyze their agricultural activities. These digital tools cover a wide range of tasks from crop rotation to pest control, and serve as a comprehensive guide for farmers seeking to improve their operations.
- Blockchain technology, known for its transparency and traceability, finds its place in agriculture. Specialists can design blockchain solutions to track the journey of agricultural products from farm to table, ensuring consumers quality and authenticity, thereby enhancing confidence in the supply chain.
- The entrepreneurial landscape is set for startups tackling specific agricultural challenges. Water management, pest control and sustainable farming practices are focal points for innovative solutions. Specialists can dig their own niche and develop solutions that meet the unique needs of Indian farmers and contribute to sustainable agricultural practices. (RAJESH, 2023)

4.2 Agricultural Digital transformation challenges

- Despite the clear potential of agtech, past experience has shown that widespread adoption can be a slow and complex process. Recent research suggests that achieving a critical mass

of users is often required to drive a tipping point, where a minority group, such as early adopters of remote farming technologies, can initiate a broader shift in social behavior.

Evidence suggests that the main barriers to technology adoption in the agricultural sector are often social and ethical in nature, rather than purely technological. A key challenge is the lack of digital literacy, particularly in rural farming communities, where inadequate infrastructure and inconsistent internet connectivity pose significant barriers.

As entrepreneurs and innovators develop new agricultural technologies, they must carefully consider these limitations and design solutions that can work effectively even in low-connectivity environments. Ignoring these contextual factors can hinder the successful deployment and adoption of potentially transformative tools and practices.

Overcoming social and infrastructural barriers to technology adoption is critical to unlocking the full potential of precision agriculture and other innovative approaches. By addressing these challenges comprehensively, the agricultural sector can accelerate the integration of advanced technologies and achieve meaningful improvements in productivity, sustainability and farmers' livelihoods.

➤ Data ownership, use, privacy and trust issues Big data is a key component of the digital transformation of agriculture. However, a lack of trust is currently a barrier to digital agriculture adoption. In addition to the barriers facing protected agriculture, farmers link concerns about transparency to a sense that political and legal control over big data is lagging behind technological developments. This raises questions about data governance, while also enabling data integration to provide actionable knowledge. (Wolfert S and Verdouw C, 2017, page 78)

➤ Another key factor is that digital agricultural technologies are affected by economies of scale. They are easier to adopt by users who can implement them at scale. This means that smallholder farmers may lag behind their larger agribusiness counterparts. This creates a gap between large and smallholder farmers, which is mirrored by the inequality between developed and developing countries. Transformative digital innovations and technologies are often not designed at the scale at which smallholder farmers operate. This emerging dynamic threatens to widen the digital divide between different categories of farmers and countries, unless the issue is carefully addressed. This will require targeted efforts to ensure that digital technologies in agriculture are accessible and relevant to all farmers, regardless of the size of their farms or level of development. (Trendov. M, Samuel, and Meng, 2019, page 16)

5. CONCLUSION

In conclusion, it is clear that digital transformation in the agricultural sector represents significant opportunities to improve productivity and efficiency, but it also faces important challenges that must be addressed.

Notable opportunities for digital transformation in agriculture include: increasing agricultural productivity, improving resource and risk management, the potential to expand market access, and Promoting sustainable agricultural development. These opportunities highlight the pivotal role of digital technologies in developing agriculture and making it more efficient and sustainable.

On the other hand, the challenges facing digital transformation include: significant investment in digital infrastructure, improving the field applicability of technological solutions, and qualifying and training workers in the agricultural sector on the use of modern technologies. These challenges could slow down the pace of digital transformation if not addressed comprehensively.

Therefore, the balance between seizing opportunities and addressing challenges The agricultural digital transformation factor is a pivotal element for the success of the agricultural digital transformation. This process requires concerted efforts from all stakeholders – governments, the private sector and farmers – to maximize the potential of agricultural digital transformation in developing and enhancing digital agriculture. food security and environmental sustainability.

In light of the points discussed in this topic, the following recommendations can be made To achieve agricultural digital transformation:

➤ Digital Infrastructure Development:

- _ Development of high-speed communications networks in rural areas.
- _ Enhance the capabilities of cloud storage and processing of agricultural data.
- _ Develop integrated digital platforms that connect various stakeholders in the sector.

➤ Promoting technical innovation in agriculture:

- _ Support research and development to find innovative digital solutions to the challenges of agriculture.
- _ Launching financing programs and incentives for startups and innovative companies in agricultural technologies.
- _ Building technology transfer clusters to accelerate the adoption of digital technologies in agricultural practices.

Building and developing the capacities of farmers and workers in the sector:

- _ Implementation of training programs to develop digital skills for farmers and agricultural extension workers.
- _ Develop digital educational content to enhance awareness of the benefits of modern technologies in agriculture.
- _ Encouraging farmers' involvement in digital agricultural extension systems.

➤ Strengthening governance and policies that support digital transformation:

- _ Develop comprehensive national strategies for digitization in the agricultural sector.

_ Developing the necessary legislation and regulations to protect agricultural data and regulate its use.

_ Allocating financial and tax incentives to encourage private sector investments in digital solutions.

By implementing these recommendations in an integrated manner, the pace of agricultural digital transformation can be accelerated, and the desired productivity gains can be achieved in the long term.

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