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Digital Transformation In Agriculture: The Role Of Precision Farming Technologies

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In the past few years, farmers have been offered a list of digital technologies that are meant to solve all the existing problems. Precision farming technologies are supposed to create a new type of farmer: precise, fast, data-based, and needing smaller plots for greater yields. The effects are known, but the path towards these positive outcomes remains relatively blurred. The question remains if the current specificity of the market will continue, or if the gap will increase because the path of the process does not correspond only to the technological point of view. The goals of this paper are to analyze the current stage of digital proliferation in agriculture and to determine if there is a specific standard in Central and Eastern European agriculture. The data used in the research was gathered from different sources and came from field experience. This study proves the general idea of the multi-use of precision farming technologies in Central and Eastern Europe, but it also underlines some specific new patterns by analyzing some examples from the region.

Keywords: Digital technologies, Precision farming, Agricultural technologies, Data-based farming, Small plots, greater yields, Agricultural innovation, Technological adoption, Central and Eastern European agriculture, Digital proliferation, Farming outcomes, Technological gap, Multi-use technologies, Agricultural standards, Field experience, Regional agricultural patterns, Precision farming adoption, Agricultural data analysis, Technological specificity, Agricultural market trends, Digital transformation in agriculture.

1. Introduction

Achieving food security in a time of climate change, population growth, and associated increases in water demand, while minimizing adverse environmental impacts, represents a major challenge for humanity in the 21st century. Success in delivering a sustainable intensification of agriculture will partly depend on the deployment of digitally driven advances, particularly for increasing yields and minimizing negative environmental impacts. Efforts to improve agriculture's environmental performance can benefit from our increasing capacity to monitor and manage plant and animal systems based on a plethora of information derived from sensors, cameras, and other remote data-collecting technologies, analyzed using artificial intelligence systems. The chapter defines precision farming and presents ways in which information science-driven technologies can be used to meet two major challenges of contemporary agricultural practice: increasing the degree of intensification of the core arable industry and mitigating climate change impact.
Many advances in precision farming techniques in the crop and livestock farming sectors usually increase the productivity and profitability of both groups. However, farmers often

show reluctance to implement digital farming solutions. Addressing all challenges of digital farming in a transparent, concerted, and inclusive fashion should allow Armenia to significantly increase the resiliency of its agriculture to climate change impact. In this regard, the EU should immediately consider including digital farming technologies in its upcoming technical support projects in the country. These technologies could further be presented as an opportunity to reduce the vulnerability of emergency food producers to the adverse effects of the climate crisis.

1.1. Background and Significance

The importance of digital transformation in almost all sectors of the economy is growing, but it is worth emphasizing that it is hardly possible to talk about the effectiveness of digitalization without taking into account the diversity of sectors. Digital transformation in agriculture does not only refer to the routine work of introducing information technologies but also earmarking budget funds for increasing bandwidth or the length of standard cable lines of telecommunications networks. The agricultural sector is diverse, ranging from large enterprises and holdings to individual farmers, representing a variety of industries. Therefore, large agro-holdings provide themselves with a narrow specialization, but it is in the agrarian niche that we are maximally reflecting scientific and technological progress. We can talk about digital transformation, which is associated with many technical restrictions that we miss only when we distill this concept incorrectly.

On the other hand, the role of agriculture as a natural sector contributing to the development of the economy is essential, especially in developing countries. Economic inequality within and between countries is rapidly declining. The problem of food security is becoming increasingly relevant for each country, primarily concerning food independence and affordability for the population. At the same time, civilization is faced with challenges such as a shortage of resources, including natural ones, and a change in consumers' preferences for products, which requires changes in the entire system of means of production provided by the sector. The processes of globalization do not bypass agriculture. The agricultural sector fully experiences the variability of external factors: fluctuations in prices on world markets, changes in climatic conditions, demand for agricultural products, etc.

Fig 1 : Technologies and precision farming

1.2. Research Aim and Objectives

The development and implementation of digital technologies in the agricultural industry play a special role, directly affecting the innovative modernization and socio-economic development of the agro-industrial complex. At the same time, the development of digital technologies, the accumulation of data, and their use in agriculture contribute to the transformation of the agricultural sector into a key generator of large amounts of various types of data in smart data. The array of digital data obtained, processed, and used in the agricultural industry as a result of various activities during the reallocation of transformative and innovative development of the agricultural industry, which was first created using various digital technologies, is used for further development of existing and creation of new additional innovative products, primarily in the established industries. The research aims to analyze and develop theoretical and practical approaches to managing the mechanisms of implementation of digital transformation of the agricultural industry and the development of agricultural holdings using precision farming technologies. The research questions are as follows: - to investigate the theoretical and methodological apparatus and existing mechanisms for the formation of digital transformation of the agricultural industry and the development of agricultural holdings using precision farming technologies; - to identify existing weaknesses in the formation and development of digital transformation of the agricultural industry and the development of agricultural holdings using precision farming technologies; - to develop and propose approaches and mechanisms for the formation of digital transformation of the agricultural industry and the development of agricultural holdings using precision farming technologies; and - to develop measures and tools for evaluating and monitoring the effectiveness of digital transformation of the agricultural industry and the development of agricultural holdings using precision farming technologies.

Equation 1 : Optimization of Fertilizer Use (Cost and Efficiency)

Precision farming often uses sensors and AI to optimize fertilizer application. The cost function C for fertilizer use can be modeled as:

$$C = C_F \times \sum_{i=1}^{n} (F_i \times A_i)$$

Where:

C_F = Cost per unit of fertilizer

F_i = Fertilizer amount applied in zone i

A_i = Area of land in zone i

n = Number of zones (defined by soil type, moisture, etc.)

The goal is to minimize C while ensuring that fertilizer is applied efficiently to increase crop yield without overuse, which can lead to environmental damage.

2. Digital Transformation in Agriculture

Digital transformation is one of the driving forces for sustainable agriculture and a central challenge for rural areas in the coming decades. Digital-enabling technologies accompany these developments and are thus also perceived as the fourth industrial revolution. From the analysis of the existing worldwide conceptual visions and long-term strategies for managing digital transformation, it was found that their main aims for the agricultural sector and rural areas at national and regional levels are to develop and implement digital platforms and their ecosystem. As an essential element of digital transformation, sustainable digital production systems are defined. The role of smart specializations, as the basis for the creation of synergistic effects and the design of complete ecosystems for sustainable digital innovation, is underlined.

It allows businesses—established players and new entrants alike—to capture a slice of what could be the agricultural innovation opportunity. Doing so would directly and indirectly transform the lives of the more than one billion people who depend on agriculture as their main source of livelihood. The question arises of how exactly digital technology can help agricultural businesses increase profitability and improve the productivity of the industry. The biggest opportunities can be found in improving resource allocation through a combination of precision farming techniques, automation, robotics, and the use of big data platforms, which may also include UAS. All these changes are led by software: everything now has a digital sense and can be used for so-called sustainable digital production. The focus is on the role of precision farming technologies as an integral part of digital transformation in the national agricultural sector, in the context of strategic directions and digital production management systems in the medium term.

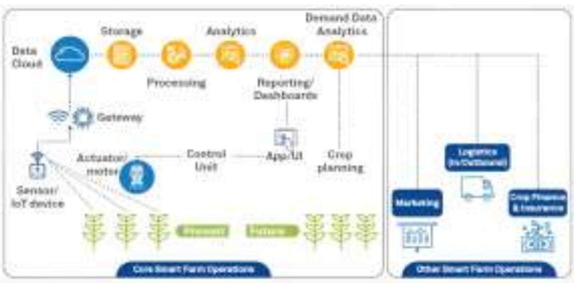

Fig 2 : Digital Transformation in Agriculture Sector

2.1. Definition and Scope

This section examines key terminologies that surround precision agriculture and precision farming technologies. These terms provide the framework for the thinking of this study. The ideology and fundamentals of precision agriculture are contained in the terms. Moreover, world regional experiences provided in this study are determined by the conceptual frontiers wrapped around the trios. These terms form the critical conceptual kernels of the global history of precision agriculture. They simulate precision ideology, showing how U.S. framing captured ideas from the annals of agricultural theory. Each concept used in precision agriculture, precision farming technologies, digital technology in agriculture, and smart farming is examined and delineated from the standpoint of precision ideology. The peculiar features and requirements of precision and the ideas that framed U.S. agriculture are critically analyzed and contrasted with contemporary global assumptions. Characteristics of precision agriculture are revisited, and the deployment and operational dynamics underlying precision agriculture are retrieved.

This study defines precision agriculture as the result of smart farming and digital technology in agriculture. It refers to a system of farm management that adopts information technology and digital equipment to ensure that crops and soil receive exactly what they require for optimum health and productivity. The concept also refers to a farming management system that customizes weather, disease, and pest control, soil and crop growth models, and remote sensing through satellites, drones, and other means. Precision farming technologies are the technologies used in such a precision agricultural system. The study employs a methodology that wraps around two precision farming ideology trios, namely precision agriculture, precision technology, and technology skills.

2.2. Key Drivers

Innovation is driven by different stakeholders who shape the environment in which innovation occurs. The key drivers of innovation can be grouped into different categories. These can be differentiated according to the field in which the drivers have their origin. Innovation economics and management studies distinguish between demand-driven and science-driven innovation. Demand-driven innovation originates from the needs of existing actors for services and products; hence, it typically involves actors in the processes who can signal the need and initiate the innovation process, such as end-users and producers, and enables market-driven innovation. Contrarily, the results from science-driven innovation predominantly originate from the field of research and development, encompass early development stages and often need more time to reach the market. Demand-driven innovation in agriculture can be considered a response to the increasing societal demands for agricultural services.

3. Precision Farming Technologies

In this work, therefore, we present a brief survey on the state of the principal precision farming technologies and their promising impacts in terms of smart use of resources, sustainability, and affluence. There are many different kinds of precision farming technologies; the choice among them depends on the type of farming and also on the local climate and soil conditions. However, there are three main classes of precision farming technologies: machinery guidance systems, variable rate technologies, and both legal and privacy issues. Each of these classes includes many different applications and purposes. Variable rate technologies mainly consist of sensor-based technologies and data management systems associated with local-space specific input measures, such as the visual or thermal infrared remote sensing sensors for crop scouting, the soil and light reflectance and transmission sensors for field scouting and fog detection, temperature and conductivity sensors for irrigation control, and unmanned aerial vehicles for vineyard and orchard scouting.

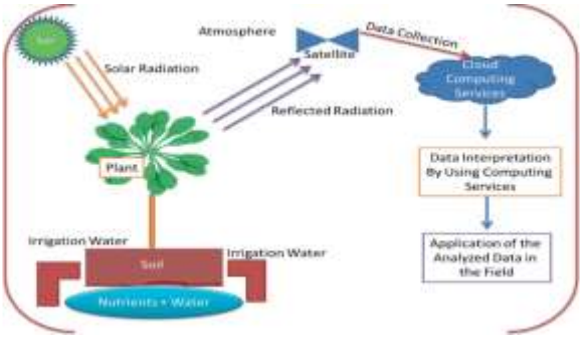

Fig 3 : Precision Farming in Horticulture

3.1. Overview and Types

The mass use of digital technologies in agricultural activities can be defined as a digital transformation of agriculture. This process is not easy to define, but we can speak about a digital transformation of agriculture when digital technology tools, related to both small devices and complex systems, capable of performing the most varied agronomic and animal production activities, can generate benefits significantly higher than those that the farmer could obtain by engaging in more manual, less efficient, and precise activities. In short, these technologies must provide satisfaction, helping to increase yields, reduce environmental impact and costs, promote services and welfare, increase traceability, and protect less qualified jobs, allowing the funds earmarked for digital innovation to return both to the company where the investment is made and to other economic sectors.

The set of technologies needed to achieve these goals has given rise to the term "smart agriculture" or "precision farming," and it has been defined as the process of using information and information technologies to manage spatial and temporal variations associated with all aspects of agriculture. Moreover, technologies have evolved since then, and the term industry 4.0 has been adapted to smart agriculture, embracing the concepts of cyber-physical systems, the Internet of Things, cloud and cognitive computing, mobile computing, and automation technologies. The interest in smart agriculture makes the concept relevant, and in fact, we have observed that technologies facilitating the process are increasingly present and used in companies. This paper provides a review and analysis of the most relevant agronomic, organizational, and economic literature on the subject to trace a detailed picture of the role of precision farming technologies in promoting digital transformation in agriculture.

Equation 2 : Crop Yield Prediction Model (Machine Learning-based)

The crop yield Y can be modeled using various variables, including weather data, soil conditions, irrigation, and input usage (fertilizers, pesticides). A machine learning model can predict the yield using historical data. An example could be:

$$Y = f(S, W, I, F, P)$$

Where:

S = Soil health/condition (e.g., pH, texture, moisture content)

W = Weather conditions (temperature, rainfall, humidity, etc.)
I = Irrigation patterns and water availability
F = Fertilizer usage and application methods
P = Pesticide usage
f = Machine learning model (could be linear regression, decision trees, neural networks, etc.)

The output Y will be the predicted yield, and the model will be trained using historical data to establish the relationship between these inputs and the yield.

3.2. Benefits and Challenges

Precision farming technologies are recognized to provide significant benefits throughout the food supply chain. The targeted and optimized use of agricultural inputs and the possibility of providing customized products to consumers are some of the benefits that farmers may gain to optimize their operations and increase their yields, while at the same time decreasing negative externalities on the environment. Besides the economic and environmental benefits, precision farming technologies also can foster less useful technological advancements. One of these advantages is the increase in the overall management level of agricultural holdings by promoting and making practical the so-called data-driven approach. This may be achieved by increased operational and management efficiency and by reducing operational risks to which the assessed production processes are exposed, also helping in the overall professionalization of the agricultural sector.

However, the resistance of farmers to employ new technologies is widely recognized; the wider applicability of precision agriculture technologies and the realization of their potential on a larger scale are subjected to scrutiny when there are institutional, organizational, and adoption-related challenges. These need to be explored, for it is particularly the early stages of the innovation process that require more attention and need to be addressed. As a response to this perceived lack of academic attention on barriers to the adoption of precision farming technologies, in-depth semi-structured interviews and a purposeful sample were utilized to explore the positions of precision agriculture expert entrepreneurs, consultants, integration experts, and computer software engineers on assumptions, cooperation and adoption, privacy and data ownership, regulations, infrastructures, education and subsidies, availability and quality of both satellite and drone technology, and labor costs. This paper reveals that the effectiveness of expert knowledge advice, cooperation, stakeholder behavior, the availability of advanced robotic systems, the lack of professional skills, the absence of subsidies to purchase drones and satellites, regulatory and privacy issues, and data ownership and infrastructures are important factors determining the success of farmer behavioral change towards the adoption of precision farming technologies, revealing the fact that these experts perceive themselves as enablers of the innovation process.

4. Case Studies

The aforementioned case studies contributed useful insights into several important specific features associated with the emerging effects of the adoption of precision farming technologies, helping smallholder farmers engage in digital transformation in agriculture. The case studies have shown that the level of farm operators' education is a key factor, but having only basic knowledge in many technological aspects, they are not always competent enough in the usage of technologies. The primary interest in the adoption of technologies should be cost-saving in both financial and labor resource usage, while profit maximization becomes an important objective after a certain period of soaking. Sometimes even irrational behavior is observed in making decisions in the context of animal behavior. Access to information and experience exchange is important for adoption; a gap also exists between the willingness and ability to use technology, especially with high differences in the influence of different agricultural machinery options used. The non-usage of technologies is affected by financial barriers because there is an issue of how cost-efficient these technologies are.

The three case studies provided a profile of smallholder farm operators already using precision farming technologies across four cultivations in Georgia, detailing the competencies these farm operators have to facilitate a transition to digital agriculture, what helps them with the adoption of technologies, and how increased technology usage due to education will contribute to agricultural development. Our case studies revealed several drivers and barriers influencing farmers' decisions to invest in precision farming technologies. The results showed that key preferences and constraints were typical for smallholder operations, including their size and structure. The case studies of utilizing even more evident opportunities, notwithstanding the awareness of precision farming technologies, also carry the aspects of their application, as well as the management and adoption of technologies in the framework of digital transformation in agriculture to be reviewed in detail.

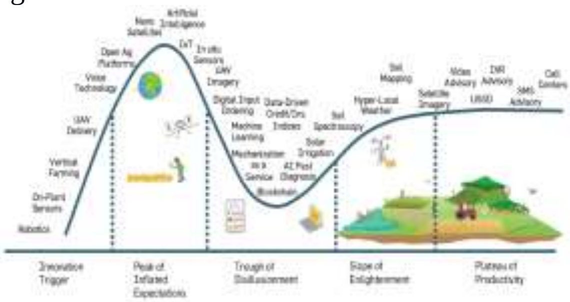

Fig 4 : Digital agriculture hype curve

4.1. Successful Implementation Cases

Argentina is a vast agricultural territory containing large agribusinesses, a significant number of small and medium-sized farmers, and billions of cultivated hectares of different crops. This is a fact not only in a specific homogeneous group of companies but also in various regions with specific resources and needs. One of the most outstanding partnerships is that between farmers who know the importance of technology and modernization, and who, with the pride of never giving up, carry a legacy of hundreds of years of hard work.

Recent advances in research and development have provided the conditions for the transformation of traditional agriculture into a prototype of modern sustainable agriculture. Precision farming consists of the application of information technology tools to traditional agronomic practices. Its objectives mainly encompass more precise crop and soil management, which are aimed at achieving the productivity increase of primary resources, sustainability, and the production improvement of various products related to agribusiness. The model used is an interactive one because it offers quick response mechanisms to achieve technological innovation adapted to increasingly unique and variable sets in space and time, which can result in environmental, economic, and technical benefits for the agricultural sector.

5. Conclusion

The high costs make the adoption of precision farming technologies at a large scale an unprofitable activity due to low or missing positive economic effects. The development of the informational infrastructure, the technology standardization and interoperability, and the availability of quality, relevant agronomic data are the major conditions to allow economies of scale and scope in the specific agricultural activities carried out following the use of precision farming technologies. Public authorities have a special role in the promotion and proliferation of precision farming technologies in this sense, through different policy instruments. Their main support actions are the establishment and the maintenance of standards and certifications; the development of knowledge transfer initiatives among farmers; the financial support to the monitoring and upgrading of the informational infrastructure in agriculture; the instrumental and financial support for the professional training and the fungibility of the labor force; the implementation of the special tax exemptions.
In many new empirical studies, the conclusions are less optimistic but the academic evidence still shows that the adoption of precision farming technologies has a positive influence in terms of productivity, return to inputs, and efficiency. However, the conditioners and the beneficiaries are more diverse and numerous. Particularly, the financial resources are not anymore the only key factor for stimulating the interest of the farmers. Digital skills and knowledge in precision farming can equally drive large-scale adoption, benefiting from the constantly improved vocational and general education over the years. Furthermore, an important success factor is the ability of farmers to understand the agronomic data and to make valuable decisions. In addition, good management needs reliable input providers, capable farm managers and workers, and innovative agri-food firms, as well as partnerships and/or knowledge transfer between technology builders, farmers, and users. Brain gain in agriculture, economic participation of young rural population, and increasing resilience of rural areas are notable outcomes described by the recent literature.

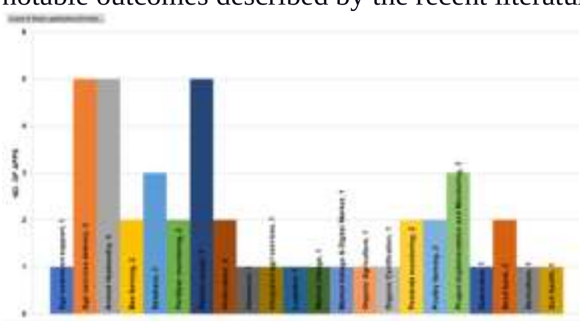

Fig 5 : Farm management and information system and services launched under digital agriculture

5.1. Future Trends and Implications

Future research should seek to better understand the potential of PF and discuss case studies. Research-based on case studies can help identify obstacles to be overcome in the implementation of technology strategies and better inform new policies and strategies based firmly on practical experiences. Work can also be extended by combining the PF with other technologies. PF is the first step and it can work very well when machines are working precisely with accurate information and can make better decisions. PF in other businesses will be very useful because of the big data structure.

One explanation for the lack of data available currently is that PF is still relatively new. Many businesses are only now beginning to explore strategic ways of managing their data and using this information to make marketing or operational investments. Some believe that cloud computing can address this issue - by harnessing and leveraging the intensity of information distribution, cloud computing makes available unprecedented and comprehensive data sets that can be analyzed to facilitate decision-making. This can be particularly significant for businesses that need additional resources to take advantage of big data. With big data, businesses can use comprehensive, rapidly changing databases to answer research questions and provide more information, quickly and accurately, to decision-makers.

Equation 3 : Yield Response to Input (Fertilizer and Water)

Precision farming can estimate the yield response to varying levels of inputs such as water and fertilizers. A simplified production function could be:

$$Y = a \cdot F^{\alpha} \cdot W^{\beta}$$

Where:

Y = Yield (in tons per hectare)
F = Amount of fertilizer used
W = Amount of water used
a = Constant (reflecting baseline conditions)
α and
β = Elasticity coefficients for fertilizer and water (representing how sensitive the yield is to changes in fertilizer and water inputs)

This model helps optimize the combination of inputs to maximize yields while minimizing environmental impact.

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