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THE INTEGRATION OF ARTIFICIAL INTELLIGENCE IN THE ACTIVITY OF AGRICULTURAL FARMS: A NEED TO ENSURE SUSTAINABILITY

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Abstract

Humanity is currently facing numerous challenges, one of the most important being that of ensuring food security, which is why agriculture is becoming one of the important branches of the economy of any country. Ensuring a sustained agricultural production, which meets both the requirements related to respect for the environment and sustainability, but also those related to food sufficiency, are aspects for which researchers are constantly looking for solutions, and the transition from traditional practices to the use of digitization, innovative technologies or of artificial intelligence, represent current and interesting topics, which is why we have the right to deepen this topic in the present work. The methodology used was based on one hand on the analysis of specialized studies, and on the other hand, quantitative research was employed for the analysis of statistical data, facilitating a detailed and substantiated understanding of the impact of AI in agriculture. This approach entailed collecting data using descriptive statistics, followed by meticulous processing and analysis of the information. It included calculating growth rates and thoroughly examining the results. These methods enabled the development of well-founded opinions, conclusions, and recommendations regarding the application of artificial intelligence in agriculture. Through this comprehensive analysis, valuable insights were gained to inform and guide the effective integration of AI technologies in the agricultural sector. The study revealed valuable insights into the benefits and challenges associated with AI in this field, which can aid in developing more efficient and sustainable agricultural practices. Evidence of the growing interest in this area includes the significant rise in investments in intelligent agricultural equipment and artificial intelligence, which surged from 1.7 billion dollars in 2019, to 4.9 billion dollars in 2021, being estimated to reach 9.6 billion dollars this year. At the same time, the conducted study also allowed us to identify the advantages and challenges facing agriculture in the adoption and implementation of digitization and artificial intelligence in specific activities.

Key words: *agriculture, farm, AI, digitization, sustainability*

INTRODUCTION

Sustainable agriculture involves the exploitation of current resources in conditions of efficiency, protecting the environment, but aiming to ensure the right of future generations to enjoy all these aspects in their turn [18]. These desires have made scientists and decision-makers constantly look for new solutions by which they can fulfill these objectives. Therefore, modern technological discoveries have also been implemented in the agricultural sector, and artificial intelligence, as the new frontier of this field, has been reached, but new solutions are still being sought to contribute to increasing the efficiency of this sector of activity that is faced with numerous challenges (climate changes, global population growth, workforce reduction, etc.) [4, 13, 16, 17].

The existence of data provided by satellites, by various sensors in the field, the accessibility to the information provided by meteorological systems have made the agricultural system have important sets of data, which have contributed to the development of artificial intelligence in this field as well, which promises important opportunities regarding the development of more sustainable agricultural practices, increasing resilience to climate change, promoting collaborative research and developing more effective policies [5, 7, 21, 24]. Artificial intelligence thus appears as a new paradigm, having a transformative role in

agriculture, which joins other technologies with a role in connecting devices and digitally activated agricultural machinery through and with the help of the Internet [6, 19].

The use of this information has contributed to the development of predictive models, systems used to detect diseases or pests, their degree of infestation, the use of intelligent irrigation systems, the optimization of resources, the reduction of the impact of agricultural activities on the environment, etc. At the same time, it is possible to increase the yields and the efficiency of the activities carried out within the agricultural farms [3, 9, 10, 12].

The role of AI in farm decision-making is complex, contributing to real-time data monitoring and analysis, forecasting and predictive modeling, resource utilization optimization, farm planning and management, decision support and process automation [1, 8, 15, 22].

Studies show that the introduction of artificial intelligence in agriculture has both opportunities and challenges, as well as the need for fair access to this type of innovative technology, which also raises ethical and ethical issues [2, 20, 25].

Interdisciplinary collaboration between researchers, farmers and decision-makers is important for the advancement of the efficient and correct use of digitization and artificial intelligence in agriculture. By promoting the exchange of information and encouraging innovation, all stakeholders in the agricultural sector can collaborate effectively. This collaboration allows them to make well-informed decisions and implement strategies that are both effective and efficient. These strategies can be applied not only at the level of individual farms but also on a global scale, ensuring a cohesive approach to agricultural development and sustainability [11, 14, 23].

MATERIALS AND METHODS

To conduct this research on the use of artificial intelligence in agriculture, we employed both documentary analysis, drawing from scientific literature, and statistical data analysis. The aim was to quantify the impact and level of AI adoption in agriculture, utilizing empirical data as a foundation.

The calculation of the annual growth rate allowed us to measure the changes related to the AI market from one year to another and to evaluate its performance over time. To calculate the percentage value, we used the formula:

$$Percentage\ increase\ (\%) = \frac{Current\ Year\ Value - Previous\ Year\ Value}{Previous\ Year\ Value} x100$$

Calculating the annual growth rate of AI in agriculture market is essential to understand the market dynamics, plan strategically, attract investments, innovate and develop relevant technologies, thus giving us a clear picture of market performance and potential, helping to to outline an image of the current situation and the development potential of this market. Additionally, it aims to enable stakeholders in Romania's agricultural sector to make informed decisions and contribute to the sustainable development of agriculture, aligning with existing European and global directions.

RESULTS AND DISCUSSIONS

Statistical data highlight the fact that artificial intelligence has the potential to revolutionize the way farms and agricultural crops are managed. According to reports published worldwide and at the European level, the adoption rate of AI technologies in agriculture is increasing, with an increasing number of farms implementing precision agriculture solutions, agricultural robots and AI-based management platforms.

Although the published data varies, the global market of artificial intelligence used in agriculture was evaluated in a report by Global Market Insight (GMI8092) published in 2024 as having a value of 1.37 billion dollars in 2022 and 1.69 billion dollars in 2023 [27]. Another report published by Market.us estimated a value of this market that was 1.2 million dollars in 2022 and 1.5 million dollars in 2023 [26].

The increase is significant, however, considering the fact that in 2018 this market was estimated at a value of 682.1 million dollars, and that of 2019 at a value of 750 million dollars. What we find is that the global market of smart agriculture technologies will have significant annual growth rates in the

coming years, these being between 20% and 33.33%.

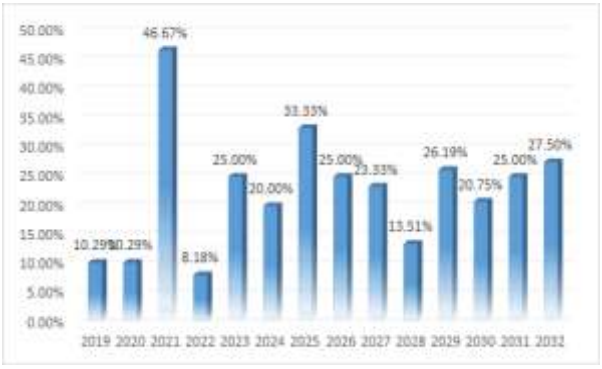

Fig. 1. The evolution of the growth rates of the use of AI in agriculture (%)
Source: own processing [26].

A determining factor in the use of technology and in the transition to digitization was the Covid-19 pandemic, also in agriculture, primarily due to the fact that people became much more open about the use of various devices that were growing anyway, and on the other hand, the fact that consumers have become more and more selective regarding the origin and quality of the food they consume, which has had an impact on monitoring the health status of crops, animals, etc. requiring the adoption and development of new technologies, which respond to market demand and leading to the development of this market. Thus, it can be seen that from growth rates of 10.29% in 2019 and 2020, in 2021 a rate of almost 47% was reached, the absolute value being 1.19 billion dollars (Fig. 1).
The size of the AI market in agriculture in $ billions is shown in Fig. 2.

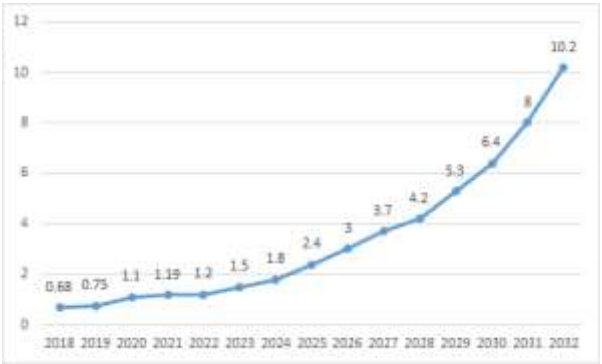

Fig. 2. Size of the AI market in agriculture ($ billions)
Source: own processing [26].

Analyzing the use of artificial intelligence by category of agricultural activities (field farming, liverstock farming, indoor farming and other activities), we find that there are no significant changes in the period 2019-2024.

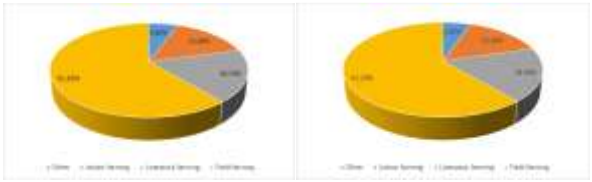

Fig. 3. The market share of AI, by category of agricultural activities, in 2019 and 2020
Source: own processing [26].

Field agriculture held and will continue to hold the largest shares, these being between 61.1% in 2019 and 2020 and 61.5% in 2023 and 2024 (Fig. 3).

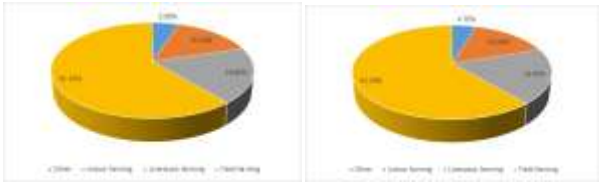

Fig. 4. The market share of AI, by category of agricultural activities, in 2023 and 2022
Source: own processing [26].

The second category of activity, highlighting the significance of artificial intelligence, is animal husbandry. During the analyzed period, this sector held shares ranging from 18.1% in 2019 to 19.1% in 2024. Similar values were recorded in the use of artificial intelligence in the field of agriculture in protected spaces, these being approximately 15% in the period 2022-2024, in insignificant decrease compared to the previous period (15.2% in 2019 and 15.1% in 2020 and 2021).

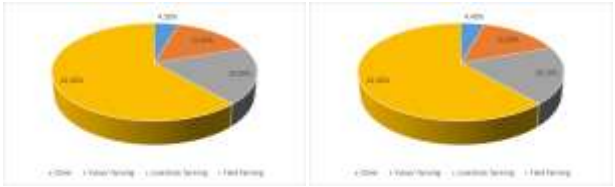

Fig. 5. The market share of AI, by category of agricultural activities, in 2023 and 2024
Source: own processing [26]

The category of other agricultural activities that use artificial intelligence also decreased during the analyzed period, from 5.6% in 2019 to 4.4% in 2024.

The data collected from different databases highlighted the fact that if in 2019, the largest share of the application of artificial intelligence was owned by precision agriculture (with approximately 30% of the total), it is estimated that in 2024 decreased by 3% of the total. However, significant decreases were recorded in the share held by the use of AI in Labor management. Thus, from a share of approximately 15% of the total held in 2019, it reached an estimated share of 8% for the current year. These changes in the weights held by the different categories of agricultural activities are due to the fact that the weights due to the introduction of drones or robots in agricultural activities have increased. If in 2019, the share held by drones, of the total, was approximately 20%, in the current year it is estimated that they hold 34% of the total, while robots, which had a share of approximately 10% in 2019, ended up they currently hold approximately 17% of the market. Market share fluctuations were recorded in the Liverstock Monitoring category, with weights between 12% in 2022 and 18% in 2021.
Other categories of agricultural activities that involve the use of artificial intelligence currently account for approximately 4%, a decrease from 2019, when they represented nearly 10% of the total.

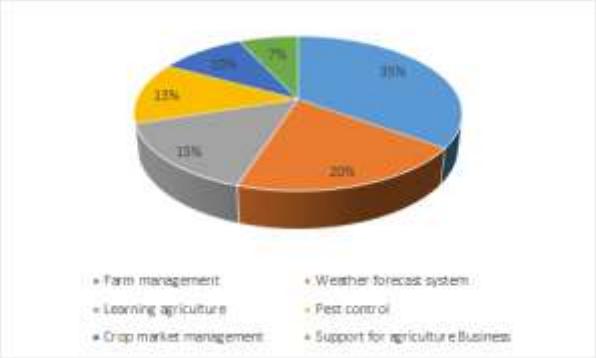

Fig. 6. The share of fields of use of AI in precision agriculture (estimate for 2024)
Source: own processing [26].

In the field of precision agriculture, the most used applications of artificial intelligence are those related to farm management (for the current year they are estimated to hold 35% of the total), followed by those related to weather forecasts (20%) and those related to the field educational (15%) (Fig. 6).

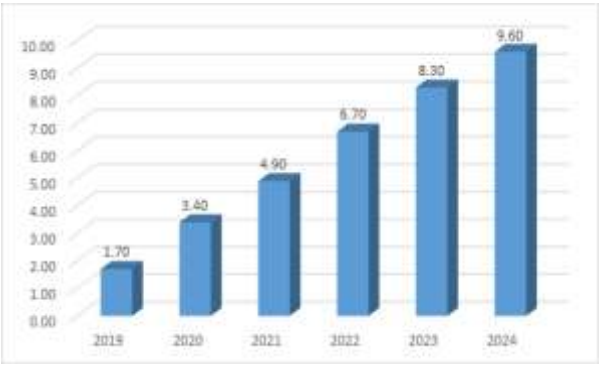

Fig. 7. The value of the investments made in intelligent agriculture in the period 2019-2024
Source: own processing.

Investments made in intelligent agriculture systems have increased significantly in the analyzed period. If in 2017 they were almost 1 billion dollars, in 2019 they reached 1.7 billion, the growth rate being 70% (Fig. 7). However, it can be observed that in 2020 the growth rate was 100%, the reason being, as we show above, the outbreak of the Covid-19 pandemic, but also the natural technological evolution. Although later the growth rates decreased to 44.12% in 2021, to 36.73% in 2022, to 23.88% in 2023 and to 15.66% in 2024 (estimated value), the value of investments increased from 1.7 billion dollars in 2019 to 9.6 billion of dollars in 2024. It was thus found that investments in smart agricultural equipment and artificial intelligence continued to grow, reaching approximately 6.7 billion dollars in 2022, as a result of the increased adoption of advanced technologies and AI solutions in agriculture. In 2023, investments rose to $8.3 billion, reflecting increased interest and expanding use of artificial intelligence and smart technologies, growth supported by continued improvements in drones, agricultural robotics, and data analytics platforms. Projections point to a continuation of the upward trend due to innovations and streamlining of agricultural processes, as more farms adopt AI solutions to optimize production and manage resources.
The analysis of this field, statistics and research allowed us to find that the applications of artificial intelligence in agriculture are diverse, covering areas such as precision agriculture, crop monitoring, livestock management and weather forecasting, etc. For example, in precision agriculture, sensors and

AI-equipped drones are used to gather various information, but there are other activities that can be adapted to these technologies (Figure 8).

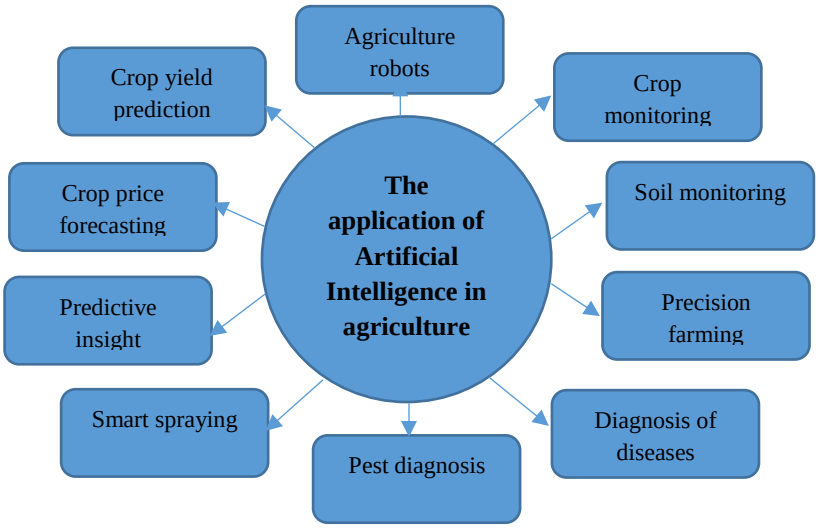

Fig. 8. The application of Artificial Intelligence in agriculture
Source: Own design and content.

Artificial Intelligence (AI) can be used in agricultural crop yield prediction through a variety of advanced methods and technologies. Thus, sensors placed in the soil can collect data about moisture, soil temperature, nutrient levels and other environmental conditions, and AI can analyze this data to predict how these factors will affect crop yields. It can also process images captured by satellites and drones to monitor plant health, identifying areas affected by disease or nutrient deficiencies, and then this data is used to make accurate predictions about future crop yields.

Machine learning algorithms can be trained on large sets of historical crop data, including factors such as soil type, crop rotation, farming practices and weather conditions, and once trained, these algorithms can predict crop yields based on current and forecast conditions. AI can integrate current climate data and weather forecasts to predict their impact on crops. Advanced climate models can also be used to simulate different climate scenarios and see how they would affect crop yields in the long term.

AI can simulate crop growth under different conditions to predict yield based on various environmental and management variables, or assess the risks associated with different farming practices and climate conditions, giving farmers valuable information to make informed decisions.

By integrating robots and establishing links between them and artificial intelligence, soil and weather data can be analyzed to determine the optimal time and place for sowing. They can also plant seeds at the right depth and spacing, ensuring maximum crop yield, apply fertilizers and pesticides exactly where they are needed, reducing waste and minimizing environmental impact, analyze data on soil moisture and weather conditions to adjust the amount of water applied in real time, detect and eliminate pests precisely, or apply chemical or biological treatments only to areas affected by disease or pests, minimizing pesticide use and reducing costs.

Agricultural robots can also be used in the harvesting or post-harvesting process. Thus, they can identify ripe fruits and vegetables by harvesting only them, without damaging the plants, or they can classify and sort agricultural products based on size, shape and color, ensuring a superior quality of products delivered to the market. These robots can work around the clock, increasing efficiency and reducing the need for manual labor. Therefore their use can bring many advantages, including

increasing efficiency, reducing costs, improving yield and minimizing environmental impact.

Another important area is related to price forecasting. Thus, artificial intelligence can be integrated into trading platforms to provide farmers and traders with recommendations on the optimal time to sell or buy, based on price forecasts, analysis of historical production price data to identify seasonal patterns and trends, or on time series of price data. In this way, future fluctuations can be predicted, based on past behavior.

Moreover, artificial intelligence can analyze global news and events, such as geopolitical conflicts, economic crises or pandemics, or even analyze market and investor sentiment in relation to global events, which can have a direct impact on crop prices. Agriculture.

However, it is important to present the empty side of the glass, and the weaknesses that accompany the use of artificial intelligence.

Thus, the researchers of this topic draw attention to the confidentiality of data, their security, considering the fact that these technologies collect, process and analyze large volumes of sensitive data, thus it is essential that farmers and technology companies adopt rigorous measures to protect this information. Farms are thus susceptible to cyber attacks that can compromise sensitive data and therefore the implementation of cyber security measures is needed. Furthermore, farmers need to be educated and trained on the importance of data security and the measures they need to take. Implementing and maintaining such data security measures can be expensive for small farmers, leading to increased costs.

In Europe, the GDPR imposes strict requirements on the collection, processing and storage of personal data. Farmers and technology companies must ensure that they comply with these regulations.

Regarding the availability and quality of data, they are essential for the effective implementation of artificial intelligence (AI) in agricultural farms, allowing accurate analyses, forecasts and useful recommendations to optimize agricultural production. The availability of data depends on farmers' access to advanced technologies, as we know, in many countries or regions, farmers do not have the necessary resources to acquire and implement these technologies, the existence of an adequate infrastructure for data collection, storage and transmission being essential. In rural areas, internet connectivity can be limited, affecting the availability of real-time data. Also, errors in data collection can lead to incorrect analysis and predictions or ineffective decisions.

Using integrated platforms that combine data from various sources can improve data availability and quality. Also, adopting uniform standards for data collection and management or ensuring collaboration between agricultural organizations and technological companies, would be aspects that could facilitate the integration and analysis of relevant information.

The integration of technical expertise in data interpretation by AI in agriculture is another sensitive aspect, necessary to ensure the relevance and accuracy of predictions and recommendations, which can be achieved through close collaboration between experts and AI developers, through the use of labeled data sets, through the development hybrid algorithms, by using simulation platforms, by creating decision support systems and by continuously calibrating models. Thus, farmers can benefit from the best agricultural practices combined with the most advanced technologies available.

Another sensitive aspect is that of ethical considerations related to the use of artificial intelligence in agriculture, which requires a holistic approach, which takes into account data privacy and security, equity in access to technology, impact on the workforce, transparency of algorithms, ecological sustainability , data ownership rights and fair distribution of benefits.

Advanced AI technologies can be expensive, which can create a disparity between large and small farmers, and between developed and developing regions. There is a risk that smallholder farmers will be excluded from the benefits of AI due to the high costs and lack of resources to implement these technologies. Automation of agricultural processes can lead to a reduction in the number of jobs available

to agricultural workers, thus affecting their livelihoods. It is important to ensure training and reskilling programs for workers affected by automation to enable them to adapt to the new demands of the labor market. Sharing data between farmers, technology companies and researchers can bring significant benefits, but it must be done responsibly and with respect for property rights.

The advantages of AI in agriculture should be equitably shared among all stakeholders, including small farmers and local communities. AI technologies should enhance the quality of life for farmers and rural communities, not merely boost the profits of large corporations. By tackling these issues, we can ensure that AI's application in agriculture delivers genuine and sustainable benefits to everyone involved in the process.

CONCLUSIONS

Artificial intelligence is an important tool that can contribute to the realization of an intelligent climate in agriculture, which can ensure a sustainable agricultural future.

The use of artificial intelligence and advanced technologies allow farmers to manage resources sustainably and ensure high-quality agricultural production, but also allow them to reduce uncertainties, optimize sales strategies and improve profitability, through more effective risk management and faster adaptation to market changes.

Continued investment growth is supported by improvements in drones, agricultural robotics and data analytics platforms. Also, initiatives such as the launch of new products and partnerships between large companies and agritech startups stimulate the development of this sector.

However, alongside the advantages of using artificial intelligence in agriculture, there are also numerous challenges. These include data confidentiality and security concerns, the high costs, and consequently the limited accessibility of these technologies, the quality of the data collected and used, but also their interpretation and the degree of confidence in what concerns the accuracy. And last but not least, ethical considerations must also be taken into account when we talk about the use of artificial intelligence.

There are solutions that will contribute to improving the current situation. Thus, we believe it is essential to invest in training farmers and agricultural staff to effectively use AI technologies and smart equipment. Also, subsidies and financial support should be provided at the policy level to help small farms adopt these advanced technologies. It is also necessary to develop clear standards and regulations for the collection and use of data in agriculture to ensure its confidentiality and security.

In conclusion, the use of artificial intelligence in agriculture has the potential to radically transform agricultural practices, providing solutions to optimize resources and enhance productivity. However, to fully achieve these benefits, challenges related to cost, education, and regulations must be addressed.

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