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PRECISION FARMING TECHNOLOGIES AND THEIR POSITIVE EFFECT ON CLIMATE CHANGE MITIGATION

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Abstract

The management of agriculture in recent times is enabling entirely new approaches to keep up with the times and to tackle one of the greatest challenges of our time, namely the climate change we are witnessing, with average temperatures rising much faster than in the last century. Nanotechnology, the Internet of Things, Big Data, Artificial Intelligence, and other technologies are making steady inroads by farmers so that they can plan more accurately for fertilisation, irrigation, yield forecasting, disease management, and risk management. These innovations, the data they collect and the solutions they present, combine to promote a variety of positive effects - economic, social and environmental. In recent decades, with the improvement and implementation of these agricultural technologies, they have contributed to environmental protection by reducing soil, water and atmospheric gas pollution, and economically enabled farmers to achieve better sustainability and financial results. The aim of this study is to assess the potential of these technologies to contribute to positive environmental impacts, food security and sustainability. The methodology of this study is to review and summarize literature, articles, reports, etc. and to compare different methods and analyze the results. The results clearly show that digital technologies will play a major role in combating climate change, but also reveal serious challenges for their mass integration due to high costs and limited access, especially observed in developing countries.

Kay words: *precision agriculture, technologies, Climate change*

INTRODUCTION

The population is projected to grow over the next 50 to 60 years, rising from 8.2 billion in 2024 to approximately 10.3 billion in the 2080’s. [33]. Agriculture plays a key role in feeding a growing population and ensuring food security on a global scale. As the number of people on the planet increases, the need for efficient and sustainable agricultural practices becomes increasingly urgent. The main function of agriculture is to produce enough food to meet growing demand. This includes not only quantitative but also qualitative aspects of production, such as ensuring access to diverse and nutritious food for all social groups. Ensuring food security requires the adoption of innovative agricultural practices, including advanced farming techniques, sustainable technologies, and strategies to adapt to changing climate conditions. Technologies such as drones, sensors and automation allow more efficient use of resources and reduced losses. In addition, agricultural development also includes improving supply chains, minimizing food waste and supporting local producers. This can contribute not only to the stability of food systems but also to economic development in rural areas. Addressing the challenges of feeding a growing population and securing food for future generations will rely on a blend of innovation, sustainable methods, and global collaboration [16].

Climate change's impact on agricultural production and food security represents a significant global challenge [4]. The global agri-food system generates an estimated 16 gigatonnes of greenhouse gases per year, accounting for around a third of global emissions. Greenhouse gas emissions are expected to continue to rise, making it impossible to achieve the Paris Climate Agreement's goal of limiting global warming to 1.5°C by 2050. Scientific research underscores the urgency of fundamentally transforming food production and consumption systems to minimize environmental harm and ensure a sustainable future for our planet [31]. There is a clear consensus amongst the scientific society that climate change is happening and inevitably will result in negative consequences to our planet if not addressed. This study aims to evaluate and summarize the perspective positives of using precision technologies in agriculture and their impact related to climate change specifically to slow down and overturn negative processes.

MATERIALS AND METHODS

The methodology is based on a framework developed by C. Parra-Lopez et al [23]. The focus of the study is on digital technologies applied in precision agriculture. Considering their role in mitigating climate change. The methodology includes a literature review, including documents, reports and articles, to explore different models and interactions between stakeholders in the development of new technologies used in agriculture. [20]. It includes a systematic review of the literature using the methods described in the study [28].

RESULTS AND DISCUSSIONS

Feeding the population is the main task of agriculture. Over the past decades, to achieve higher yields, we have been using more and more mineral fertilizers, and chemicals such as insecticides, herbicides, pesticides, etc., the situation is similar in animal husbandry. All this leads to negative consequences for the environment: pollution of water resources, pollution and degradation of soils, air pollution, a decrease in biodiversity and disruption of natural ecosystems are observed.
On the other hand, huge advances in digital technologies are increasingly entering agriculture, modernizing the sector, and leading to improved efficiency and sustainability of the sector. Precision technologies allow for the optimization of water and fertilizer use, improve soil management methods, and can lead to a reduction in negative environmental impacts. These technologies are changing the face of the entire sector, making it attractive to younger generations. Combining traditional agriculture with new technologies is the foundation for achieving sustainable practices that support climate change adaptation efforts.
Number of studies Parra-Lopez [21], [25], [30] and [35] summarized that the definition of climate change should include global warming, extreme weather events, changes in precipitation patterns and changes in other climatic phenomena over time, which can lead to significant and permanent changes in the climate and weather of the Earth. These changes are already happening and knowing that a significant part of this is caused by agriculture, we should look for practices to reduce its impact. Climate change caused by agricultural practices is a topic of discussion and part of the bigger picture set out in the EU Green Deal [6].
The agricultural and food system in Europe, backed by the Common Agricultural Policy, is recognized worldwide for its leadership in safety, reliable supply chains, nutrition, and quality. However, it now faces the challenge of setting a global benchmark for sustainability. Transitioning to a more sustainable food system, while maintaining food accessibility and affordability, can deliver significant environmental, health, and social advantages, along with promoting fairer economic outcomes [14].
The latest UN report on the emissions gap emphasizes that limiting the global temperature rise to 1.5°C above pre-industrial levels is essential to prevent severe and far-reaching consequences of climate change. Achieving this target requires reducing greenhouse gas (GHG) emissions by 42% by 2030 and by 56% by 2035. Specifically for agriculture and the food industry, the targets are as follows: The amount of greenhouse gas emitted per calorie of food produced must be reduced by 28% by 2030 and by 35% by 2035, while yields per hectare must increase by 16% by 2035 and by 22% by 2035 [9]. The European Union's bold climate policy aspires to make Europe the first continent to achieve net-zero CO2 emissions by 2050. To achieve the ambitious goal, an interim target of reducing emissions by at least 55% by 2030 compared to 1990 levels has been set by the European Green Deal. This strategy attempts

to ensure a sustainable food system is functioning in the European Union (EU). The main strategic achievements are to ensure that food production and food consumption are contributing to environment protection and public health and also are creating a better environment for economic growth in the agricultural sector [3].

There is a set of specific targets and timeframes in place:

- 25% of EU agricultural land to be organic by 2030
- 50% reduction in the use of chemical pesticides by 2030
- 30% reduction of mineral fertilizers by 2030 [3].

New modern technologies and their application in agriculture are key factors for achieving the targets set in the Green Deal [7]. Production experience alongside the implementation of the technologies of Precision agriculture can transform the current situation leading to more efficient processes, better production quality and mitigating the negative impacts and risks to the environment [22].

In recent years, precision agriculture has made significant progress and can be described as a sustainable systemic solution that increases the quality and quantity of production, while reducing costs, human intervention and the uncertainty caused by natural variability [18]. This concept emphasizes key challenges such as risk mitigation, environmental sustainability, and ecological degradation, which are critical in the 21st century. Precision agriculture is increasingly recognized as a valuable management strategy, aligning closely with global objectives like sustainable food production [15]. Precision agriculture is a modern scientific approach in the agricultural sector that integrates advanced technologies and innovative methods to optimize the management of agricultural activities. By using tools such as global navigation systems (GPS), satellite and remote sensing, unmanned aerial vehicles (drones) and analytical platforms for data processing, this approach aims to increase the productivity and economic efficiency of agricultural systems, while reducing costs and minimizing risks associated with the production process. A basic principle of precision agriculture is sustainable resource management, which includes the efficient use of water, soil, fertilizers and energy. By localizing the specific needs of individual areas in agricultural areas, the system optimizes the allocation of inputs, reducing ecological footprints and helping to protect the environment. The scientific value of precision agriculture also extends to its ability to provide solutions for adaptation to climate change and variable weather conditions. Thanks to real-time monitoring systems and adaptive management, this approach ensures the sustainability of agricultural systems and the long-term stability of production. Precision agriculture represents a transformational model in agricultural science that not only supports sustainable development and food security but also provides a practical basis for building a sustainable global food system.

C. Parra-Lopez et al. examine Digital technologies in agriculture for climate change adaptation and mitigation, analyzing the key digital technologies used in precision agriculture: Remote Sensing, Big Data, Artificial Intelligence, Internet of Things, Nanotechnology, Robots, and Blockchain. They explore how the application of these technologies contributes to addressing the challenges posed by climate change [21]. The integration of digital technologies with agriculture offers a transformative solution to the dual challenges of climate change and global food security.

Remote Sensing (RS)

Remote sensing (RS) involves collecting information about objects or areas without physical contact, using airborne or satellite platforms. These platforms carry sensors that operate across optical, thermal, and microwave spectral ranges [30]. Remote sensing (RS) plays a significant role in modern agriculture by providing valuable data and insights that improve productivity, efficiency, and sustainability. By using satellite, drone, or aircraft-based sensors, farmers and agricultural managers can monitor and manage crops, soil, and environmental conditions more effectively.

Table 1. Digital technologies- Contribution to climate change and mitigation

Digital technology	Contributions to climate change and mitigation
Big Data	1. Enhances the efficiency of resource utilization and supports precision agriculture practices 2. Reduces environmental impact and promotes sustainable soil management 3. Customizes environmental monitoring to address targeted requirements 4. Strengthens crop resilience by enabling genetic improvements 5. Optimizes water usage and enables early detection of stress factors 6. Lowers greenhouse gas emissions by advancing residue management techniques
Remote Sensing	1.Boosts efficiency in water usage 2. Promotes decision-making through data-driven farm management 3. Enables monitoring of environmental trends and changes effectively 4. Enhances the resilience of crops and ensures stable yields. 5. Facilitates accurate and sustainable utilization of agricultural inputs and resources. 6. Advances yield prediction and minimizes potential risks 7. Strengthens protection of crops against soil erosion
Internet of Things	1. Facilitates accurate land suitability analysis and optimal crop placement 2. Integrates real-time weather data to support precision farming practices 3. Safeguards forests and promotes the preservation of biodiversity 4. Enhances crop monitoring and ensures consistent yield stability 5. Minimizes fertilizer waste and mitigates environmental impact 6. Strengthens disaster preparedness and resilience in agriculture
Artificial Intelligence	1. Optimizes irrigation systems and promotes efficient water conservation 2. Improves the precision of climate modeling and supports informed farm management decisions 3. Decreases reliance on pesticides and herbicides 4. Enhances environmental sustainability practices 5. Speeds up the development of crops resistant to climate stress
Nanotechnology	1. Enhances carbon sequestration efforts and contributes to climate change mitigation 2. Boosts nutrient use efficiency while minimizing greenhouse gas emissions
Robots	1. Lowers emissions from pesticides and fertilizers 2. Enhances safety measures on farms 3. Ensures precise harvest timing to reduce waste 4. Speeds up the detection and management of crop diseases
Blockchain	1. Promotes sustainable agricultural practices 2. Enables carbon trading and contributes to climate change mitigation efforts 3. Optimizes land management practices to minimize environmental impact 4. Enhances food quality and ensures greater transparency across the supply chain

Source: Own figure based on [21].

Remote sensing has revolutionized agriculture over the past decade by providing advanced tools to monitor, manage, and improve agricultural practices. It supports precision agriculture by providing accurate and actionable insights, enabling better decision-making and resource optimization.

The main applications include: Crop Monitoring, Assessing Windbreak Effectiveness, Water Management and Climate Monitoring, Intelligent real-time data collection, Yield forecasting and many other applications.

Crop Monitoring- Remote sensing technology enables real-time monitoring of crop health by detecting common issues such as stress, nutrient deficiencies or diseases through spectral data analysis. This helps optimize the use of agricultural inputs such as fertilizers and pesticides, ensuring they are applied effectively and sustainably. As a result, crop resilience improves, yields become more consistent and crop improvement programs benefit from targeted insights.

Assessing Windbreak Effectiveness- Remote sensing technology provides valuable data to assess the effectiveness of windbreaks in protecting soil health and preventing erosion. By analyzing this data, farmers can optimize water use efficiency and improve the effectiveness of other farming practices, such as mulching and contour farming, leading to better resource management and sustainable agricultural outcomes.

Water Management and Climate Monitoring- Remote sensing provides essential data for effective water resource management, including mapping irrigation systems and optimizing water use, which is of utmost importance to farmers. It also tracks environmental trends and climate-related changes, providing insights that support the development of effective adaptation strategies in agriculture. This helps farmers respond to climate variability and manage water resources much more sustainably.

Intelligent real-time data collection- When combined with other digital technologies used in precision agriculture, remote sensing enables real-time, data-driven management of agricultural operations. This integration improves soil health management, supports and optimizes water use efficiency, and ensures the sustainable application of agricultural inputs such as precision irrigation systems, leading to more efficient and environmentally friendly agricultural practices.

Yield forecasting- By predicting yields with precision, remote sensing helps farmers plan better and mitigate risks associated with market or environmental uncertainties. This makes the planning process easier and a very practical tool [21]. It helps make informed decisions regarding input management and resource allocation, increasing the efficiency and profitability of the farm as a whole.

Big Data (BD)

Big Data refers to huge and complex volumes of data that cannot be effectively managed, processed, or analyzed through traditional information management methods and tools. It involves the processes of collecting, storing and analyzing data that is generated at high speed, comes from various sources and is often unstructured or semi-structured. Big Data (BD) involves gathering, storing, processing, and analyzing vast volumes of information from varied and diverse sources [12].

In agriculture, BD offers numerous opportunities to address climate change through its applications in crop, water, climate and soil management. By enabling precision agriculture, data-driven decision-making, smart farming and predictive modelling [27]. BD can improve productivity and support climate change adaptation and mitigation strategies. Big data is transforming agriculture and environmental management, enabling more precise, efficient, and sustainable practices. It has enabled agriculture to become a sector where decisions are made based on information. Here are some key applications and their benefits: Early Detection of Water Stress in Orchards, Predictive Modeling for Water and Pest Management, Genomics for Crop Improvement, Regenerative Management of Crop Residues, Environmental Monitoring and Predictive Modeling, Sustainable Soil Resource Management.

Predictive Modeling for Water and Pest Management- The use of big data allows for accurate prediction of water shortages, which are a major problem for farmers in many parts of the world, as well as the prediction of pest outbreaks. By analyzing patterns and trends, it helps optimize resource allocation, ensuring efficient water use and targeted pest control. This data-driven approach supports precision agriculture, reducing waste and preventing the overuse of agricultural resources, leading to sustainable agricultural practices.

Early Detection of Water Stress in Orchards- The use of technology, based on collected data, helps indicate early signs of water stress and therefore helps with better and more precise irrigation control, which leads to yield improvements and better plant development.

Genomics for Crop Improvement- The large database of genetic information about plants is used to analyze and improve their qualities. It also contributes for better crop performance in severe weather conditions – droughts, colds and diseases.

Regenerative Management of Crop Residues- Using Big Data can help with better management of residues. Avoid burning and implement new methods. Considering the amount of Greenhouse gases coming from agriculture, using these methods can significantly decrease the Carbon footprint.

Environmental Monitoring and Predictive Modeling- Environmental Monitoring and Predictive Modeling - This approach, like the previous one, uses Big Data to tailor strategies to accurately track environmental changes. Analyzing trends and predicting future conditions, helps reduce emissions and supports the creation of integrated management plans that ensure adequate environmental protection and sustainability

Sustainable Soil Resource Management- Within this approach Big Data can be used to track models of behavior and based on the collected information to create models for the future. This can be strategically integrated in businesses to reduce emissions and promote sustainability.

RS and BD technologies are emerging as key tools for improving agricultural practices and environmental monitoring. They enable crop monitoring, yield prediction, and real-time data collection, supporting both adaptation (e.g., crop improvement) and mitigation (e.g., sustainable use of inputs). By providing accurate and timely information, these technologies help farmers make data-driven decisions to increase resilience, stabilize yields, and optimize resource use. Beyond farm management, BD applications address broader environmental challenges, such as water scarcity, pest outbreaks, and climate change. Furthermore, BD in genomics offers the potential to improve crop resilience through genetic adaptation.

Internet of Things (IoT)

The Internet of Things (IoT) has emerged as a key tool in addressing climate change. IoT-enabled devices, such as sensors, gather extensive data on soil moisture, weather patterns, and fertilizer levels. This data empowers farmers to optimize irrigation systems and enhance the overall efficiency of agricultural production [13].

Automated agricultural machines, like precision tractors, simplify essential tasks such as planting, sowing, and pesticide application, reducing the need for manual labour and optimizing resource use.

IoT is essentially an advanced system of computing devices, mechanical components, and digital machines, all equipped with unique identifiers [17].

Internet of Things (IoT) technology collects, transmits, and analyzes data from various sensors and devices embedded in precision agricultural equipment, machinery, and environmental systems. This technology helps farmers optimize their operations, and increase efficiency and productivity while promoting farm sustainability. Here are some key applications: Automated Crop Monitoring, Natural Disaster Early Warning, Weather Monitoring Systems, Soil Quality Assessment, Precision Fertilizer Management, Weather Monitoring Systems, and Forest Monitoring Systems.

Automated Crop Monitoring- It improves crop monitoring, leading to more stable yields and ensuring the implementation of effective and sustainable agricultural practices. This approach allows for timely interventions, when needed, leading to optimized crop health and effective resource management**.**

Natural Disaster Early Warning- Improves farmers' preparedness and response to natural disasters by helping communities and farming systems become more resilient to climate-related events such as floods, droughts storms, and hailstorms. This proactive approach minimizes damage and supports faster recovery.

Weather Monitoring Systems- Provides real-time weather data, enabling precision farming, and helping farmers make informed decisions about crop planting, irrigation, and resource management, leading to more efficient farming practices.

Soil Quality Assessment- It contains valuable information about soil qualities such as health and land suitability. This data gives the farmers the opportunity to make informed decisions, so they can maximise performance.

Precision Fertilizer Management- A useful tool, where precise fertilizer use is essential. Helps to ensure that the plants are receiving the right amounts of nutrients and at the same time reduce costs and minimize waste and environmental impact.

Forest Monitoring Systems- It is a tool used for the protection of forests, biodiversity preservation etc. Playing a key role in reducing risks for the environment [21].

Artificial Intelligence (AI)

Artificial Intelligence (AI) in recent years has become one of the most widely used tools to resolve problems and improve processes in agricultural businesses. The algorithms used in the process analyze large volumes of data, which enables farmers to make more informed decisions. AI though relatively new is more and more used by the farmers. Usually described as a system with a certain degree of autonomy. The applications of AI have a significant potential to address climate change [26].

The application of AI-based technologies has significant potential to address climate change and its impacts. The development of these technologies in agriculture is at a very early stage compared to other production sectors [11]. Artificial intelligence-based applications in agriculture: Pest identification and monitoring, climate forecasting and management, weed management, genomic and phenotypic analysis for crop breeding, water use optimization and irrigation efficiency.

Pest Identification and Monitoring- Pest Identification and Monitoring - AI helps to more accurately identify and monitor pests and diseases, enabling precise control. This reduces the need for widespread pesticide use, promoting environmental sustainability and more effective disease and pest management, supporting the sustainable use of agricultural resources.

Climate Forecasting and Management- The use of AI significantly improves the accuracy of climate models, providing farmers with much more accurate weather forecasts. This allows for better planning and informed decision-making, helping them adapt to changing climate conditions and anticipate and mitigate potential risks.

Weed Management- The use of artificial intelligence helps reduce the use of herbicides by ensuring precise weed control, which inevitably leads to reduced environmental impact and improved crop protection.

Genomic and Phenotypic Analysis for Crop Breeding- AI accelerates the process of growing climate-resistant crops (cold-resistant, drought-resistant, resistant to certain diseases, etc.) by analyzing genetic and phenotypic data, which allows for more precise and effective selection of characteristics that improve the adaptability of crops to changing environmental conditions.

Water Use Optimization and Irrigation Efficiency- The use of artificial intelligence in precision irrigation leads to efficient use of water resources, which is very applicable in the context of water shortages in many regions of the planet [21].

IoT and AI represent the future of precision agriculture, which is set to develop very rapidly in the future. Artificial intelligence applications, such as pest detection, weed control, and genomic analysis for crop breeding, support the sustainable use of raw materials and crop improvement. Importantly, these technologies reduce environmental impact and accelerate the development of climate-resilient crops. IoT enhances AI by offering real-time monitoring through a network of sensors and automated systems. From crop monitoring to precision fertilizer management and early warning systems for disasters, IoT improves both adaptation and mitigation efforts, enabling timely interventions that reduce waste, and emissions, and increase farm resilience.

Nanotechnology:

Nanotechnology in agriculture is used to implement new solutions and improve the efficiency of agricultural practices by manipulating matter at the nanoscale (billionths of a meter), which these technologies provide. By using agricultural nanotechnology to reduce the particle size of biochar, nanomaterials with improved physical properties and better biological efficiency for soil applications are created [24]. This improved product has an increased ability to improve carbon sequestration and reduce the very harmful emissions of methane and nitrous oxide from agricultural activities, contributing to efforts to reduce pollution from agriculture [23]. The use of microorganisms for the production of nanoparticles, which act as ecological nano factories. The use of diverse microorganisms: bacteria, fungi, yeasts, actinomycetes and microalgae, for the synthesis of nanoparticles presents great opportunities in agriculture, in adapting to climate change. With the help of these microorganisms, nano fertilizers and nano pesticides can be created, which provide a controlled release of active components in the process. [1].

Based on nanotechnology, innovative solutions have been created to improve soil conditions, which leads to efficient use of agricultural raw materials, hence more effective carbon capture in the soil and reduction of emissions into the atmosphere. The main applications of these technologies in agriculture are the production of nano charcoal and, the development of nano fertilizers and nano pesticides.

Production of Nano char for Soil Enhancement- As mentioned, it helps in capturing and storing carbon in the soil, greatly increasing its carbon storage potential and playing a major role in combating climate change.

Development of Nano fertilizers and Nano pesticides- their use improves sustainable agriculture by maximizing the efficiency of nutrient use and reducing greenhouse gas emissions released into the atmosphere, contributing to environmentally friendly agricultural practices.

Nanotechnology in agriculture offers a variety of opportunities for innovative solutions and sustainable development of agriculture and to address climate challenges such as drought, and extreme temperatures, through effective resource management.

Robotics:

Robotics in agriculture contributes to precision and efficiency, enabling tasks such as targeted spraying, automated harvesting, and disease and pest detection. These technologies reduce the use of pesticides and fertilizers, reduce emissions from agriculture, and improve crop health and yield stability. Robots are used in many sectors, but they are not yet widespread in agriculture, despite the advantages they provide, the main reason for this is their high cost. In recent years, they have increasingly begun to enter agriculture, providing innovative solutions to optimize processes, increase efficiency, and reduce the environmental footprint by reducing greenhouse gas emissions [19]. Robots have begun to find applications in performing various activities in agriculture: weed control [8], harvesting [29], disease recognition in large fields and their rapid treatment [17], pest control, etc. Robots Applications in Agriculture: Targeted Spraying, Disease Detection in Crops, Automated Harvesting.

Targeted Spraying- Robots with precision spraying capabilities minimize pesticide emissions, reduce fertilizer use, and ensure accurate dosing and precise application. This technology increases environmental safety and protects workers while promoting efficient use of resources. This leads to sustainable use of agricultural resources, fewer chemicals, higher efficiency, and many other benefits.

Disease Detection in Crops- Advanced robotic systems help in crop diagnostics and management, leading to improved overall plant health and promoting environmentally responsible farming practices. These systems use precision systems for early detection and management of plant diseases using advanced technologies such as computer vision, artificial intelligence, and a wide array of sensors.

Automated Harvesting- Automated harvesting robots are transforming modern agriculture by improving efficiency, reducing waste and ensuring optimal harvest times.

They go a long way towards addressing the acute labour shortage in agriculture. Robots replace or enhance traditional manual harvesting processes. Automated harvesting is an important step towards sustainable and resource-efficient agricultural systems that offer solutions to the challenges of modern agriculture [21].

The introduction of robots in agriculture provides opportunities for more precise and efficient management of agricultural processes. Precision spraying, precise detection of diseases and harvesting. The use of these innovations allows for to reduction of the need for the use of pesticides and fertilizers, which leads to lower emissions, while improving crop health and yield stability, which is the main goal of farmers. Another big advantage is the automation of agricultural processes, thus reducing the need to hire people. This can help solve the problem of labour shortages in agriculture.

Blockchain:

Blockchain is a technology that provides a reliable and transparent way to store and exchange data in the agricultural sector. It uses a decentralized network of computers to record information in a chain of blocks that is difficult to change or manipulate. Each block contains a record of information about the previous block. The main advantage of blockchain technology is the ability to create and store a digital history of transactions, providing increased immutability, transparency, and traceability.

Blockchain technology improves transparency and traceability in food production, and supports climate change mitigation through carbon offset projects and adaptation strategies, while promoting quality in the agricultural supply chain [10].

Blockchain technology in agriculture is transforming supply chain management by improving transparency and traceability, ensuring trust in quality and ethical practices. Blockchain allows for real-time traceability of raw materials, which prevents fraud and improves food safety, which is of utmost importance. Smart contracts automate agreements between farmers, suppliers and traders, accelerating the speed of payments and significantly reducing administrative costs. According to [34]: technologies such as Blockchain are very important for farmers, offering opportunities to support their adaptation to climate change through climate finance. The opportunities are for small farmers through easy access to tokenized credit platforms, microinsurance, group lending, collective financing, etc. In addition, blockchain can be used to easily monitor investments and assess the results of improved climate change adaptation management techniques. In the context of climate change mitigation, blockchain can help create a global carbon data community that can facilitate the monitoring and evaluation of carbon reduction efforts, as well as support the development of carbon markets. Blockchain Applications in Agriculture: Soil Improvement and Nutrient Management, Enhancing Food Production Transparency and Traceability and Monitoring Carbon Offset Initiatives.

Soil Improvement and Nutrient Management- The application of optimized land management techniques and the rational use of resources leads to significant improvements in soil health. These approaches minimize the negative impact on the environment, contributing to increasing the sustainability of agrarian ecosystems. ***Enhancing Food Production Transparency-*** By using traceability systems, promotes improved food quality and provides transparency throughout the supply chain. This approach supports sustainable agricultural practices and contributes to broader climate change adaptation goals. ***Monitoring Carbon Offset Initiatives-*** It supports the effective monitoring and evaluation of carbon offset projects, ensuring transparency in carbon trading. Accurate measurement and management of carbon emissions are important for reducing the impact of climate change. In food production, Blockchain technology offers opportunities to improve transparency and traceability of processes. By implementing greenhouse gas emission compensation projects and good adaptation strategies, these precise innovations indirectly lead to climate change mitigation and environmental protection. On the other hand, they shorten the supply chain of agricultural products, contribute to better quality and promote transparency [4].

The introduction of digital technologies into precision agriculture not only brings a step forward in solving the food security problems facing humanity, but it is increasingly clear that limiting the environmental impact of the sector is increasingly important. Digital technologies provide greater opportunities for this. Table 1 illustrates how digital technologies in precision agriculture contribute to reducing the effects of climate change. The introduction of digital technologies into agriculture is leading to increased efficiency and sustainability of agricultural systems while reducing their environmental footprint and contributing to global efforts to address climate change. Key to progress is expanding access to these technologies, especially in developing countries and to smallholder farmers. This includes improving infrastructure, reducing technology costs, and increasing farmers' digital skills, which will enable them to better take advantage of new technologies [2].

The development of digital technologies provides many options for improving traditional agricultural practices, which enhance sustainability in the long term The implementation of digital technologies in agriculture is also imperative in the context of the global challenges facing humanity[5]. On the other hand, precision technologies can lead to a transformation of rural areas that can lead to economic growth [14].

CONCLUSIONS

Based on the study, the following conclusions can be drawn:

The introduction of digital technologies in agriculture can be a major factor in reducing the impact of climate change and protecting the environment.

Precision agriculture has undergone development in the last decade due to the rapid introduction of new or improved technologies. Despite its undeniable benefits, there are many limiting factors to its implementation in developing countries, where technology uptake has been very slow compared to developed countries. The main reasons are high costs, lack of sufficient information, and trained professionals.

The aforementioned factors are also limiting the use of these technologies by smallholder farmers.

Digital technologies will be a key resource for sustainable development in the future and the modernisation of Agriculture. The transformation of the sector is making it more attractive to young people. The automation of processes leads to a reduction in the sector's dependence on labour, which is a major challenge for the farmers.

The potential of precision technologies to increase production efficiency and optimise the resources used plays an essential role in the growth of the sector.

The advent of digital technologies has an impact in the fight against climate change and will allow for more accurate measurement of reduced greenhouse gas emissions from the sector.

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