Keywords: *Smart Agriculture, digitalization, agriculture, IoT, artificial intelligence, precision farming, agro-innovation, water-saving technologies.*

Annotatsiya. *Ushbu maqolada O‘zbekiston qishloq xo‘jaligini raqamlashtirish jarayoni hamda* ***Smart Agriculture (Aqlli qishloq xo‘jaligi)*** *texnologiyalarining iqtisodiy samaradorligi tahlil qilinadi. Tadqiqotda zamonaviy raqamli texnologiyalarning O‘zbekiston qishloq xo‘jaligidagi o‘rni, ularning ishlab chiqarish samaradorligiga ta’siri va istiqboldagi rivojlanish imkoniyatlari baholangan. Tadqiqotda statistik tahlil, qiyosiy tahlil va tavsifiy tahlil usullaridan foydalanilgan. O‘zbekistonning ko‘rsatkichlari Niderlandiya, AQSh, Isroil va Yaponiya kabi raqamli qishloq xo‘jaligi rivojlangan davlatlar tajribasi bilan taqqoslangan.*

Tadqiqot natijalari shuni ko‘rsatdiki, ***IoT (Internet of Things)*** *sensorlari, sun’iy intellekt, dron texnologiyalari, GPS (Global Positioning System) asosidagi aniq dehqonchilik hamda suvni tejovchi sug‘orish tizimlarini o‘z ichiga olgan Smart Agriculture texnologiyalari qishloq xo‘jaligida resurslardan foydalanish samaradorligini sezilarli darajada oshiradi, suv sarfini kamaytiradi, hosildorlikni ko‘paytiradi va ishlab chiqarish xarajatlarini optimallashtiradi. Shu bilan birga, O‘zbekistonda ushbu texnologiyalarni joriy etishga to‘sqinlik qilayotgan asosiy omillar sifatida raqamli va moliyaviy infratuzilmaning yetarli darajada rivojlanmaganligi hamda fermerlarning raqamli texnologiyalar bo‘yicha bilim va ko‘nikmalarining cheklanganligi aniqlandi.*

Maqolada xalqaro ilg‘or tajribalarni joriy etish, innovatsion loyihalarni qo‘llab-quvvatlash hamda fermerlarning raqamli kompetensiyalarini rivojlantirish orqali O‘zbekiston qishloq xo‘jaligini raqamlashtirishni jadallashtirish bo‘yicha amaliy tavsiyalar ishlab chiqilgan.

Kalit so‘zlar: *aqlli qishloq xo‘jaligi, raqamlashtirish, qishloq xo‘jaligi, IoT, sun’iy intellekt, aniq dehqonchilik, agroinnovatsiyalar, suvni tejovchi texnologiyalar.*

Аннотация. *В данной статье рассматривается процесс цифровизации сельского хозяйства Узбекистана и оценивается экономическая эффективность технологий Smart Agriculture (умного сельского хозяйства). Исследование направлено на выявление роли современных цифровых технологий в развитии сельского хозяйства Узбекистана, оценку их влияния на эффективность сельскохозяйственного производства, а также определение перспектив дальнейшего развития отрасли. В работе использованы методы статистического, сравнительного и описательного анализа. Показатели Узбекистана сопоставлены с опытом стран, являющихся мировыми лидерами в области цифрового сельского хозяйства, включая Нидерланды, США, Израиль и Японию.*

Результаты исследования показывают, что внедрение технологий Smart Agriculture, включая датчики IoT (Интернета вещей), искусственный интеллект, беспилотные летательные аппараты (дроны), системы точного земледелия на основе GPS (глобальной системы позиционирования) и водосберегающие технологии орошения, способствует повышению эффективности использования ресурсов, значительному сокращению потребления воды, росту урожайности и снижению производственных затрат.

Вместе с тем выявлены основные препятствия для широкого внедрения технологий умного сельского хозяйства в Узбекистане, среди которых недостаточное развитие цифровой и финансовой инфраструктуры, а также ограниченный уровень цифровой грамотности фермеров.

В статье предложены практические рекомендации, направленные на ускорение цифровизации сельского хозяйства Узбекистана посредством внедрения передового международного опыта, поддержки инновационных проектов и повышения квалификации фермеров в области цифровых технологий.

Ключевые слова: *умное сельское хозяйство, цифровизация, сельское хозяйство, Интернет вещей (IoT), искусственный интеллект, точное земледелие, агроинновации, водосберегающие технологии.*

JEL: Q16, O33, C88

INTRODUCTION

Agriculture is one of the strategic sectors of the economy of each country. Especially in developing countries, this sector is of great importance in providing the population with food products, creating employment and increasing export potential. Agriculture also occupies one of the leading positions in the economy of Uzbekistan. In recent years, the country has been implementing large-scale reforms aimed at modernizing the agricultural sector, increasing production efficiency, and introducing modern technologies. In this regard, the digitalization process is emerging as one of the main factors in the development of agriculture.

Traditional agricultural methods have problems such as inefficient use of water resources, difficulties in predicting yields, high production costs, and the impact of climate change. Smart Agriculture technologies are an important solution to solving these problems. Smart Agriculture is a system for managing agricultural processes based on artificial intelligence, the Internet of Things (IoT), drones, GPS monitoring, sensor systems, and big data. With the help of these technologies, farmers have the opportunity to use resources more efficiently, increase productivity, and reduce production costs.

World experience shows that the use of digital technologies in developed countries has significantly increased agricultural efficiency. For example, countries such as the Netherlands, the USA, Japan and Israel are widely using precision farming, automated irrigation systems and artificial intelligence-based monitoring systems. As a result, limited land and water resources are being used with high efficiency in these countries.

Uzbekistan has also been taking significant steps towards the digitalization of agriculture in recent years. The introduction of electronic land monitoring, agro-platforms, water-saving irrigation technologies and remote monitoring systems is creating new opportunities in the agricultural sector. However, there are some problems related to the level of technological knowledge of farmers, infrastructure capabilities and financial resources in the widespread introduction of digital technologies.

The main objective of this study is to analyze the development status of Smart Agriculture technologies in Uzbekistan and assess their economic efficiency. During

the study, the experience of Uzbekistan is compared with international practice, the impact of digitalization on agricultural production, existing problems and future development directions are studied.

LITERATURE REVIEW

In recent years, the digitalization of agriculture has become one of the main goals of agricultural policies at global levels. The concepts of Smart Agriculture, Precision Agriculture, and Agriculture 4.0 involve in their visions an increase in production efficiency due to the implementation of modern information and communication technologies in agriculture. In scientific research, such technologies as artificial intelligence (AI), the Internet of Things (IoT), GPS, GIS, drones, remote sensing technologies, and Big Data analytic systems are presented as effective ones in terms of managing agricultural resources, forecasting harvests, and optimizing costs (Wolfert et al., 2017; Liakos et al., 2018; Klerkx et al., 2019). These technologies allow farmers to ensure effective data analysis in real-time and make appropriate decisions based on that analysis.

The economic efficiency of smart agricultural technologies has been studied by many researchers. Zhang et al. (2002) and Lowenberg-DeBoer and Erickson (2019) stress that precision farming technologies help cut fuel, mineral fertilizer, and water consumption and improve productivity. Recent studies highlight the importance of digital technologies, such as crop monitoring, disease detection, and irrigation under artificial intelligence and Internet of Things control, in decreasing production costs and increasing farm profits (Papadopoulos et al., 2024; Kumar et al., 2024; Assimakopoulos et al., 2024). The Food and Agriculture Organization of the United Nations and the Organization for Economic Co-operation and Development acknowledge digital technologies' role in contributing to food security, resource conservation, and sustainable agricultural development.

Large-scale reforms are also being implemented in Uzbekistan to modernize and digitize agriculture. In particular, special attention is paid to increasing production efficiency through the introduction of electronic land monitoring, water-saving irrigation systems, agro-platforms and remote monitoring technologies. The reports of the World Bank, FAO and Asian Development Bank indicate that the efficient use of water resources, adaptation of agriculture to climate change and the widespread introduction of digital technologies in Uzbekistan are priority areas of the country's agrarian policy. At the same time, the digital literacy of farmers, the high cost of technologies and the insufficient development of digital infrastructure in rural areas are indicated as the main factors hindering the widespread introduction of smart technologies.

An analysis of the existing scientific literature shows that although the technical advantages and environmental efficiency of smart agricultural technologies have been widely studied, there are relatively few studies devoted to a comprehensive assessment of their economic efficiency in the conditions of Uzbekistan. In particular, there is a lack of scientific research assessing the investment efficiency of the introduction of digital technologies, the impact on production costs, the level of water saving and the

long-term impact on productivity. Therefore, this study serves to fill the existing scientific gap by analyzing the development status of Smart Agriculture technologies in Uzbekistan, assessing their economic efficiency, and comparing them with international experience.

METHODS

This study aims to assess the process of digitalization of agriculture in Uzbekistan, in particular, the economic efficiency of Smart Agriculture technologies. The study examined the level of use of modern digital solutions in agriculture, their production efficiency, resource utilization capabilities, and comparison with international experience. A comprehensive approach was chosen as the research methodology, using statistical analysis, comparative analysis, descriptive analysis, and scientific literature review methods.

The main database of the study was formed by reliable international and national statistical sources. Data on Uzbekistan were obtained from official data published by the National Statistics Committee of the Republic of Uzbekistan, the Ministry of Agriculture, Invest Uzbekistan, and state programs. For international comparison, data from the Food and Agriculture Organization of the United Nations (FAO), the World Bank, the Organization for Economic Cooperation and Development (OECD), and international agricultural technology studies were used.

The period of 2018–2025 was selected as the research period. The main reason for choosing this period is that it was during these years that Uzbekistan implemented large-scale reforms aimed at digitizing economic sectors, developing electronic management systems, and introducing innovative technologies in agriculture. At the same time, this period is also considered a stage of rapid development of artificial intelligence, IoT devices, and automated agricultural technologies internationally.
The study analyzed the following technologies as key elements of the Smart Agriculture concept:

Table-1. Main directions of Smart Agriculture technologies.

Technology	Application	Expected economic efficiency
IoT sensors	Monitoring soil moisture and temperature	Reducing water and fertilizer consumption
Drone technologies	Monitoring crop fields	Reducing labor costs
GPS systems	Precision farming processes	Saving fuel and resources
Artificial intelligence	Yield forecasting and analysis	Improving decision-making quality
Satellite monitoring	Monitoring the condition of the soil and crops	Reducing crop losses

Several analytical methods were used during the study. First, descriptive statistical analysis was used to study the dynamics of agricultural production indicators, the introduction of water-saving technologies, and the use of digital services in Uzbekistan. This method identified the current state, development trends, and key changes.

The second method was comparative analysis. The level of development of Uzbekistan in Smart Agriculture was compared with the experience of countries that widely use digital technologies in agriculture. In particular, the Netherlands, the USA, Japan, and Israel were selected. The reason for choosing these countries is that they have leading experience in the effective use of limited natural resources, achieving high yields, and using innovative agricultural technologies.

In addition, the study used graphical and tabular analysis methods. With the help of graphs, changes over time, differences between countries, and the economic impact of digital technologies were visually represented.

The methodological basis of the study was the model "digital technologies → resource efficiency → production volume → economic result". Through this approach, not only the technical but also the economic effectiveness of Smart Agriculture technologies was assessed. For example, the reduction of water consumption through water-saving irrigation systems, the increase in productivity through sensor technologies, and the reduction of production costs through digital monitoring were analyzed.

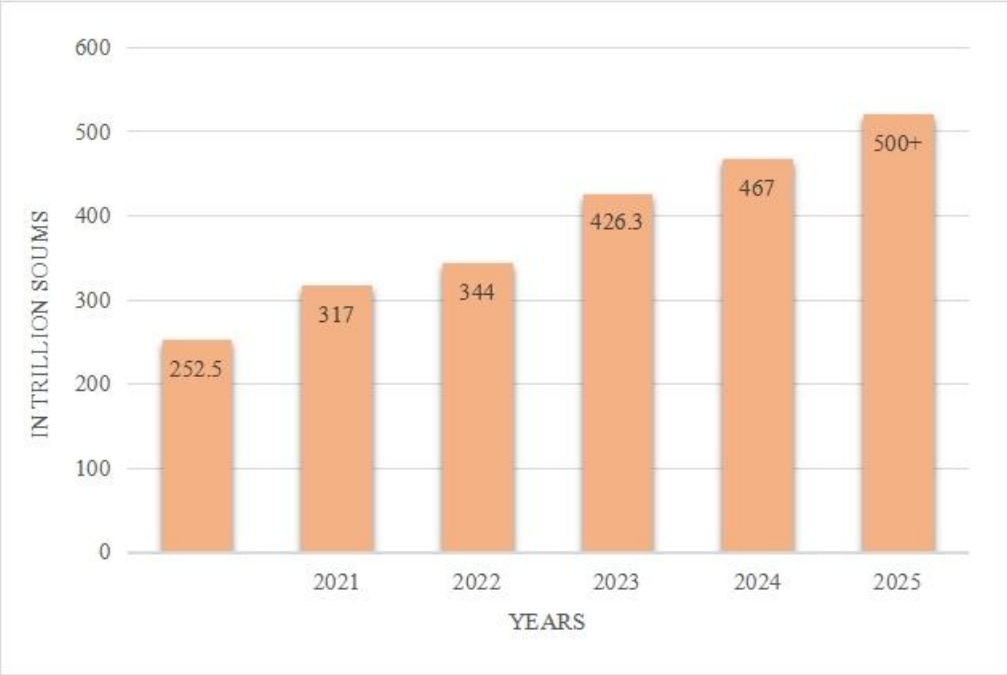
The study also conducted a qualitative analysis to identify existing problems and determine future development directions. This took into account the level of digital literacy of farmers, the cost of technologies, infrastructure capabilities, and state support mechanisms.

In general, the chosen methodological approach allows for a comprehensive assessment of the current state of Smart Agriculture technologies in Uzbekistan, comparison with international experience, and the development of effective development strategies in this area.

RESULTS

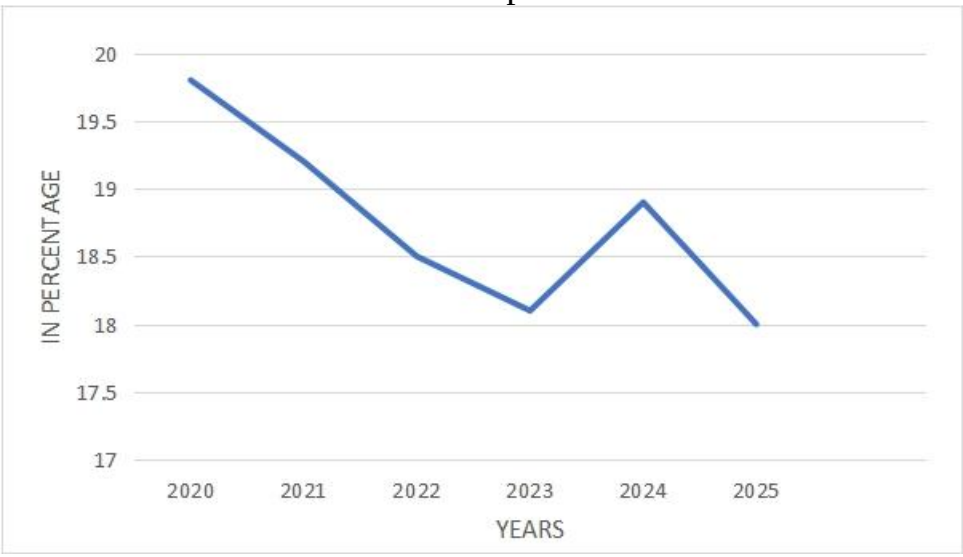
The results of the study show that the process of digitization of agriculture in Uzbekistan has been developing significantly in recent years. The use of modern technologies in the agricultural sector serves not only to improve production processes, but also to effectively use resources, improve product quality and strengthen the competitiveness of agricultural products. Agriculture in Uzbekistan is one of the important sectors of the country's economy, and the introduction of digital technologies in it is considered one of the main directions of sustainable development.

The analysis shows that a number of projects related to digitization in the agricultural sector were implemented in Uzbekistan during 2020–2025 (graphic 2). In particular, work on the introduction of electronic land monitoring systems, agrocluster management platforms, remote monitoring tools, and water-saving technologies has been expanded. These processes allow for the transition from traditional management methods in agriculture to a data-based management system.



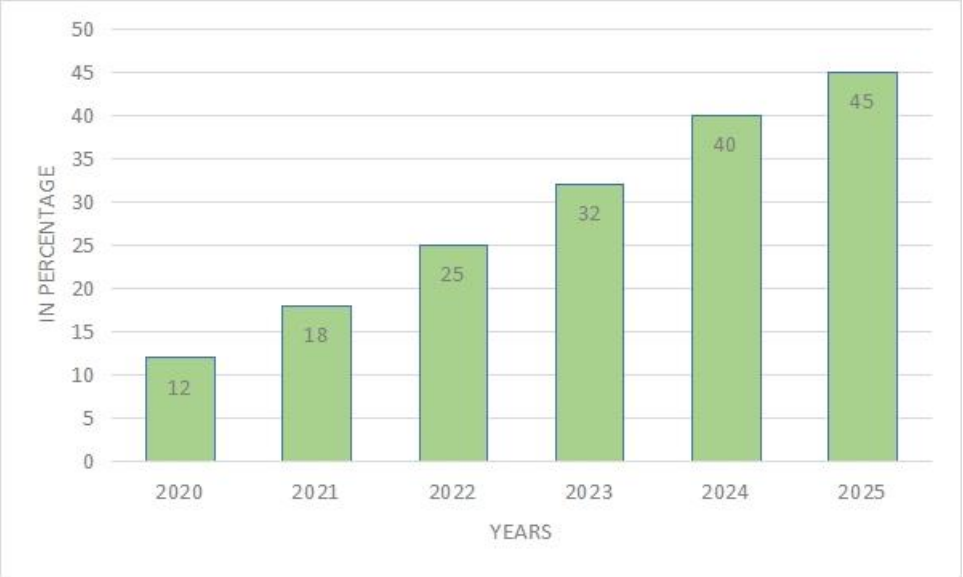
Graphic -1. Main economic indicators of the agricultural sector in Uzbekistan (2020–2025).

The graphic 1 shows that the volume of agricultural production in Uzbekistan during 2020–2025 has shown a consistent growth trend. In particular, the volume of production, which amounted to 252.5 trillion soums in 2020, is projected to reach 426.3 trillion soums in 2023, and more than 500 trillion soums by 2025. This growth indicates an increase in production efficiency as a result of reforms being implemented in the agricultural sector, modernization of production processes, introduction of innovative and digital technologies, as well as measures to support farms by the state. This trend confirms that the stable growth of agricultural production serves to strengthen the country's food security, expand export potential, and further increase the importance of the agricultural sector in economic development.



Graphic-2. Dynamics of changes in the share of agriculture in gross domestic product (GDP) in Uzbekistan during 2020–2025.

The graphic 2 shows the dynamics of changes in the share of agriculture in gross domestic product (GDP) in Uzbekistan during 2020–2025. As can be seen from the graph, the sector's share in GDP decreased from 19.8 percent in 2020 to 18.1 percent in 2023, but recovered to 18.9 percent in 2024. This situation indicates that the strategic importance of agriculture in the economy remains, while structural changes are taking place in the structure of the economy as a result of the rapid development of other sectors, such as industry and services. Also, the reforms being implemented in the agricultural sector to digitize, introduce innovative technologies, and increase production efficiency are contributing to the sustainable development of the sector.



Graphic-3. Coverage of water-saving technologies in agriculture.

The graphic 3 data shows that the scale of implementation of water-saving technologies in Uzbekistan has been steadily expanding during 2020-2025. In particular, if in 2020 the share of areas covered by these technologies was 12 percent, by 2025 this figure reached 45 percent. Such positive dynamics is the result of state programs and investment projects implemented to widely introduce drip irrigation, sprinkler irrigation and other modern irrigation methods. The use of water-saving technologies helps to reduce irrigation water consumption, improve land reclamation, and increase the productivity of agricultural crops. At the same time, these technologies are an important component of the Smart Agriculture concept and play a significant role in ensuring the digitalization of the agricultural sector and rational use of resources. As can be seen from the data, the volume of agricultural production has increased from year to year. At the same time, the share of agriculture in the overall economy has remained relatively stable. This indicates that other sectors of the economy are also developing. One of the most important results is the increase in the coverage of water-saving technologies. Because in the conditions of Uzbekistan, the efficient use of water resources is a decisive factor for the sustainability of agriculture.

An important indicator in assessing the economic efficiency of Smart Agriculture technologies is the reduction of water, labor and production costs. With the

help of modern sensor systems and automated irrigation technologies, farmers have the opportunity to obtain accurate information about the condition of crops.

Compared to international experience, Uzbekistan still lags behind developed countries in the use of Smart Agriculture technologies. However, reforms implemented in recent years are helping to reduce this gap. In particular, the experience of the Netherlands and Israel widely uses water management, automated greenhouses, and precision farming systems.

Table-2. International comparison of the use of Smart Agriculture technologies.

Country	Precision farming level	IoT and sensor use	Water saving technologies
Netherlands	Very high	Widespread	Above 90%
USA	High	Widespread	High
Israel	High	Widespread	Very high
Japan	High	Developed	High
Uzbekistan	Developing	Early-growing	Increasing

This table compares the level of use of Smart Agriculture technologies in different countries. While in developed countries digital technologies have become an integral part of agricultural production, in Uzbekistan this process is at the stage of active development.

The results of the study show that Smart Agriculture technologies are creating a significant economic opportunity for Uzbek agriculture. For example, precise irrigation systems can reduce water consumption by 30-50 percent, while sensor technologies can increase the efficiency of fertilizer use. In addition, rapid monitoring of crop areas through drone and satellite monitoring can help reduce yield losses.

Table-3. Economic impact of Smart Agriculture technologies.

Technology	Key result	Efficiency
Drip irrigation	Reduce water consumption	30–50% savings
IoT sensors	Precise monitoring	20–35% resource savings
Drones	Crop control	Reduce labor costs
AI systems	Prediction	Increase productivity

The table shows the impact of Smart Agriculture technologies on agricultural production efficiency. These technologies create opportunities for farms to reduce costs and improve production results.

Overall, the research results show that the process of digitization of agriculture in Uzbekistan is developing positively. Although the use of Smart Agriculture technologies is not yet fully developed, the existing results indicate that this direction will play an important role in increasing the future competitiveness of the country's agricultural sector.

DISCUSSION

The results of this study show that the process of digitization of agriculture in Uzbekistan has great potential for increasing the efficiency of the agricultural sector. The introduction of Smart Agriculture technologies is helping to transfer agricultural production processes from traditional management methods to a modern data-based management system. As shown in the results of the study, the use of water-saving technologies, remote monitoring systems, IoT devices, and precision farming elements is creating opportunities for efficient use of resources.

Agriculture in Uzbekistan is a sector that is largely dependent on natural resources, especially water resources. In the context of water scarcity and climate change in the country, increasing production efficiency has become a pressing issue. Therefore, one of the greatest advantages of Smart Agriculture technologies is the ability to save water and other production resources. For example, using drip irrigation and automated irrigation systems, it is possible to reduce water consumption and at the same time increase crop yields. This ensures not only economic efficiency, but also environmental sustainability.

When comparing the results of the study with the experience of developed countries, it was found that Uzbekistan still has great potential for development in this area. In particular, the experience of the Netherlands shows that digital technologies, automated greenhouses and precise control systems can be used to achieve high yields even in conditions of limited land. The experience of Israel can serve as an important example for Uzbekistan in water resource management and the development of innovative irrigation technologies.

At the same time, there are a number of problems in the widespread introduction of Smart Agriculture technologies in Uzbekistan. The first problem is the insufficient formation of farmers' knowledge and skills in the use of digital technologies. The digitalization process is slowing down due to the fact that many small and medium-sized farms do not fully understand the advantages of modern technologies or do not have the opportunity to use them.

The second problem is the high cost of introducing technologies. IoT sensors, drones, artificial intelligence systems and automated equipment require initial investments. It can be especially difficult for small farms to independently purchase such technologies. Therefore, it is necessary to strengthen the mechanisms for state subsidies, preferential loans and support for innovative projects.

The third problem is related to the level of development of digital infrastructure in rural areas. For Smart Agriculture technologies to work effectively, there must be a stable Internet connection, modern communication tools and technical support systems. The limited availability of these opportunities in some remote areas hinders the introduction of digital technologies.

In addition, it is important to strengthen cooperation between higher education institutions, research centers and agricultural enterprises. Training specialists in Smart Agriculture, organizing practical training for students and farmers, and introducing scientific developments into production will serve the development of this sector.

Based on the results of the study, the following strategic directions can be proposed for Uzbekistan. First, it is necessary to establish digital agriculture centers based on the climatic and production characteristics of each region. These centers can provide practical assistance to farmers in selecting technologies, using them and analyzing results.

Secondly, it is necessary to develop the production of local agrotechnology's. Currently, many modern technologies are imported, which increases their cost. By expanding local production, technologies can be made more accessible and affordable for farmers.

Thirdly, it is important to develop an agricultural database. Creating analytical systems based on Big Data on yield, weather conditions, soil conditions and market demand will improve farmers' decision-making.

In general, Smart Agriculture technologies are an important tool for modernizing Uzbek agriculture, increasing its competitiveness and ensuring its sustainable development. Despite the existing problems, the continuation of the digitalization process will create new economic opportunities in the agricultural sector and help strengthen Uzbekistan's position in the international agricultural market.

CONCLUSION

The results of this study show that the digitalization of agriculture and the introduction of Smart Agriculture technologies in Uzbekistan are an important strategic direction for increasing the efficiency of the agricultural sector, rational use of resources, and modernization of production processes. With the help of modern digital technologies, there is an opportunity to reduce the problems of water scarcity, high production costs, difficulties in managing yields, and climate change in agriculture.

During the study, the experience of Uzbekistan was compared with the experience of developed countries. The results showed that while Smart Agriculture technologies have become an integral part of agriculture in countries such as the Netherlands, the USA, Japan, and Israel, this process is still at the development stage in Uzbekistan. Nevertheless, in recent years, the expansion of water-saving irrigation systems, electronic monitoring, agroplatforms, and digital management systems has yielded positive results.

Based on the analysis, it was determined that the use of Smart Agriculture technologies serves to reduce water consumption, increase productivity, optimize production costs, and improve farmers' decision-making capabilities. In particular, IoT sensors, drones, GPS systems, and artificial intelligence-based analytics tools provide accurate and efficient management in agriculture.

However, there are also some problems in the digitalization process. In particular, the insufficient level of digital literacy of farmers, the high cost of technologies, infrastructure limitations in rural areas, and the lack of specialists are hindering the widespread implementation of Smart Agriculture technologies. To solve these problems, it is necessary to strengthen cooperation between the state, scientific organizations, and the private sector.

In the future, for the development of digital agriculture in Uzbekistan, it is important to expand farmer training programs, provide financial support for innovative technologies, develop local agrotechnology production, and improve digital infrastructure in rural areas.

In conclusion, Smart Agriculture technologies are a future development model for Uzbek agriculture, which not only increase economic efficiency, but also serve to ensure food security, environmental sustainability, and international competitiveness.

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