Machinery & Energetics
Vol. 15, No. 3. 2024

Journal homepage:
https://technicalscience.com.ua/en

UDC 631.587
DOI: 10.31548/machinery/3.2024.47

Bakytbek Askaraliev*
PhD in Technical Sciences, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0002-7180-2671

Kasiet Musabaeva
PhD in History, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0002-9145-9866

Baratali Koshmatov
PhD in Technical Sciences, Acting Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0003-1601-1284

Kanat Omurzakov
Postgraduate Student, Senior Lecturer
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0001-8654-3767

Zhyparkul Dzhakshylykova
Postgraduate Student, Senior Lecturer
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Srt., Bishkek, Kyrgyz Republic
https://orcid.org/0009-0007-5259-3054

Development of modern irrigation systems for improving efficiency, reducing water consumption and increasing yields

Abstract. The study was conducted to examine modern irrigation systems aimed at improving water efficiency, reducing water consumption and increasing crop yields. The study analysed the environmental and socio-economic aspects of modern irrigation systems, including their impact on the environment and social sustainability of agriculture. The study determined that the use of modern irrigation systems, such as drip irrigation and IoT-based automatic control systems, can significantly improve the efficiency of water use in agriculture. Data analysis demonstrated that such systems can reduce water consumption by up to 50% while increasing yields by up to 30%. The use of agricultural drones to monitor field conditions and precisely regulate irrigation helps to improve plant health and reduce labour costs. The study also determined that water recycling and reuse systems can significantly reduce the use of freshwater, which is especially important in regions with limited water resources. In general, modern irrigation technologies demonstrate high efficiency

Article's History: Received: 21.03.2024; Revised: 18.06.2024; Accepted: 15.08.2024.

Suggested Citation:
Askaraliev, B., Musabaeva, K., Koshmatov, B., Omurzakov, K., & Dzhakshylykova, Zh. (2024). Development of modern irrigation systems for improving efficiency, reducing water consumption and increasing yields. *Machinery & Energetics,* 15(3), 47-59. doi: 10.31548/machinery/3.2024.47.

*Corresponding author

and economic feasibility, contributing to the sustainable development of agriculture. The study proved that the use of computer modelling and forecasting of plant water requirements provides optimal conditions for their growth, which further contributes to an increase in yields. The results of the study can be used in practice to develop and implement more efficient and environmentally friendly technologies in irrigation and drainage systems, which helps to reduce the negative impact on the environment through more efficient use of water resources and reduction of water runoff

Keywords: agricultural drones; computer modelling; plant needs forecasting; optimal conditions for growth; water use

INTRODUCTION

The development of modern irrigation systems represents a drive to improve the way water is used in agriculture. Key areas of development include the introduction of advanced technologies such as drip irrigation and automated control systems based on the Internet of Things (IoT). These technologies not only help to optimise water consumption but also improve the accuracy and regularity of irrigation, which in turn leads to a significant increase in yields. Another important aspect is the use of agricultural drones to monitor the condition of fields and precisely regulate irrigation, which reduces labour costs and increases the overall efficiency of the process. Additionally, the introduction of water recycling and reuse systems minimises the use of fresh water, which is especially important in conditions of limited water resources. Thus, modern irrigation technologies are aimed at creating sustainable and cost-effective solutions for agriculture.

This study is critically important in the context of the current challenges associated with climate change and sustainable agricultural development. Efficient use of water resources is becoming increasingly important as the population grows and freshwater availability deteriorates. Modern irrigation and watering systems, represented by drip irrigation, automated technologies and data-driven management systems, promise to significantly improve water savings and increase the production results of agricultural enterprises. The research is also needed to confirm the effectiveness and economic feasibility of these technologies, which will contribute to their widespread adoption and sustainable development of agriculture in the future.

The problem existing in the area under study is the need to increase the efficiency of water use in agriculture. Drip irrigation, studied by R. Sidhu *et al.* (2021), has proven to be effective in agriculture due to the precise distribution of moisture to plant roots, which contributes to improved yields and economic efficiency. M. Hamdi *et al*. (2021) confirmed the economic feasibility of IoT-based automatic irrigation systems, pointing to their ability to reduce operating costs and efficiently use water resources. J. Gómez & A. Tascón (2021) demonstrated that the use of agricultural drones to monitor fields increases the efficiency of irrigation and fertiliser management, contributing to improved plant health and yields. F. Parada *et al*. (2021) demonstrated that water recycling systems in agriculture significantly reduce freshwater consumption and improve the sustainability of water use in resource-limited environments. G. Malhi *et al*. (2021) highlighted the need to adapt irrigation systems to a changing climate to maintain sustainable agricultural production. S. Naghdi *et al*. (2021) revealed the significant potential of computer modelling for optimising water resources in agriculture. W. Loiskandl & R. Nolz (2021) emphasised the importance of taking environmental factors into account when developing new technologies in the agricultural sector in a study on the environmental aspects of irrigation systems. G.N. Curry *et al*. (2021) discussed the socio-economic impacts of new technologies in agriculture, emphasising the need to consider social aspects when developing water use policies. W. Zhang *et al*. (2024) identified challenges and proposed solutions for sustainable water use in regions with limited water resources. Lastly, N. Dwijendra *et al*. (2022) highlighted the importance of innovation for sustainable agricultural development in a changing climate. However, there are still gaps in optimising water recycling systems, predicting plant needs using computer modelling, studying the socio-economic impact of new technologies, and understanding the environmental aspects of modern irrigation systems. These gaps need to be further explored to develop more comprehensive and sustainable solutions for agricultural water management.

The study aims to investigate modern irrigation and watering systems aimed at improving water efficiency, reducing water consumption and increasing crop yields. Research goals include:

1. Assessment of the environmental aspects of modern irrigation and watering systems to minimise the negative impact on the environment when using water resources in agriculture.
2. Analysis of the technical characteristics of agricultural drones.
3. Investigation of the potential of water recycling systems to reduce freshwater consumption in conditions of limited water resources.

MATERIALS AND METHODS

A detailed analysis of various technologies in irrigation and watering systems was carried out, including drip irrigation, automatic irrigation systems and spot irrigation. The study included an assessment of the effectiveness of each of these technologies in different climatic and soil conditions, as well as their ability to accurately distribute water directly to plant roots. The advantages, such as minimising water losses and improving yields through optimal use of resources, as well as the disadvantages associated with the technical and operational aspects of implementing these systems, are analysed.

The socio-economic aspects of introducing modern irrigation technologies were also analysed. The economic feasibility of using such systems and their impact on reducing operating costs in agriculture and improving resource management are assessed. The environmental, social and economic aspects of modern irrigation systems were assessed. The environmental impact of such technologies on the environment was analysed, including the potential impact on land resources, aquatic ecosystems and biodiversity. The researchers studied the socio-economic aspects of introducing new technologies in agriculture. The paper analysed the impact of these technologies on employment in the agricultural sector, changes in farm incomes and public support for such innovations. The study examined in detail the possibilities of using the DJI Agras T30 agro-industrial drone (China) to monitor the condition of fields and optimise irrigation. Its technical characteristics and ability to collect data on soil moisture, plant health and the general condition of the fields were analysed. The use of this drone allows agricultural enterprises to conduct more frequent and detailed monitoring, which contributes to accurate and efficient management of irrigation and fertilisation.

The use of computer models to predict plant water requirements and optimise irrigation regimes was evaluated. Mathematical models were developed based on data on climatic conditions, soil types and the needs of different crops. The study of water recycling systems in agriculture included an in-depth analysis of their efficiency and potential to improve the sustainability of the agricultural sector. Technologies were analysed, including the use of treated wastewater and other secondary water sources for crop irrigation. Assessment of the impact of recycling systems on the sustainability of the agricultural sector was prioritised. These technologies help improve the resilience of agriculture to climate change and environmental challenges. A significant reduction in the use of fresh water is not only economically beneficial but also contributes to the preservation of water resources for future generations, which is an important aspect of sustainable agricultural development strategies. The following formulas were used in the study. The formula for calculating the volume of water for drip irrigation (1):

$$W_d = \frac{A \times ET_c \times K_c}{E_a}, \tag{1}$$

where: W_d – volume of water for drip irrigation (l/day); A – field area (m²), ET_c – evaporation and transpiration demand (mm/day); K_c – crop coefficient (dimensionless); E_a – system efficiency (dimensionless, usually 0.9-0.95 for drip irrigation).

The formula for calculating the volume of water for automatic irrigation (2):

$$W_a = W_m \times \left(1 - \frac{R}{P}\right), \tag{2}$$

where: W_a – the volume of water for automatic irrigation (l); W_m – the maximum irrigation volume (l); R is the volume of precipitation (mm); P is the threshold soil moisture level (mm).

The formula for calculating water savings (3):

$$S_j = W_t - W_j, \tag{3}$$

where: S_j – water savings (l); W – traditional watering volume (l); W_j - watering volume using IoT (l). The formula for calculating the efficiency of spot irrigation (4):

$$E_p = \frac{W_p}{W_t}, \tag{4}$$

where: E_p – the efficiency of spot irrigation (dimensionless); W_p – the volume of water for spot irrigation (l); W_t – the traditional volume of irrigation (l).

The formula for calculating freshwater savings (5):

$$S_w = W_t - W_r, \tag{5}$$

where: S_w – water savings (l); W_t – traditional watering volume (l); W_r – recycled water volume (l).

The formula for calculating the drone efficiency (6):

$$E_d = \frac{W_d}{W_m}, \tag{6}$$

where: E_d – drone utilisation efficiency (non-dimensional); W_d – volume of water when using drones (litres); W_m – maximum watering volume (litres).

The formula for calculating optimal fuel volumes (7):

$$W_c = A \times ET_c \times K_c \left(\frac{1}{E_c}\right), \tag{7}$$

where: W_c – optimal irrigation volume (l); A – field area (m²); ET_c – evaporation and transpiration demand (mm/day); K_c – culture coefficient (dimensionless); E_c – model efficiency (dimensionless).

These formulas demonstrated how different irrigation systems can optimise water use and increase yields, which is especially important in the context of global climate change and water scarcity.

RESULTS

Modern irrigation systems are being actively developed to improve efficiency, reduce water consumption and increase yields. Drip irrigation is one of the most efficient and modern irrigation systems that significantly increases agricultural productivity while minimising the use of water resources. This technology is based on the principle of delivering water directly to the roots of plants through a network of tubes, drippers and emitters. This not only improves the quality of irrigation but also reduces water losses, which is especially relevant in the context of global climate change and water scarcity.

Unlike traditional irrigation methods such as sprinkling or surface watering, drip irrigation provides precise water dosing, delivering it directly to the plant root zone. This significantly reduces water losses due to evaporation and surface runoff, which is especially important in arid regions where water resources are limited. This ensures that the plants receive the necessary amount of moisture, which contributes to their better growth and higher yields. In addition, drip irrigation helps improve soil quality. As the water is delivered directly to the roots, the risk of surface crusting and soil erosion is reduced. This, in turn, promotes better oxygen penetration to the roots of plants and improves their overall health. It is also worth noting that drip irrigation allows for more efficient use of fertilisers and pesticides that can be added to the irrigation system, which reduces the cost of their use and reduces the negative impact on the environment.

For drip irrigation, the initial costs include the cost of equipment (tubes, drippers, filters, pumps) and installation work, which can range from $1,500 to $3,500 per hectare. The operating costs for this system include maintenance, replacement parts, energy for the pumps and regular cleaning of the system, which amount to about $100-$300 per hectare per year. Drip irrigation is an effective and sustainable solution for modern agriculture (Bansal *et al.*, 2021). It can significantly increase the yield and quality of agricultural products with minimal water consumption. In the context of global climate change and increasing water scarcity, drip irrigation is becoming an important tool for ensuring food security and sustainable development of the agricultural sector. Drip irrigation provides precise water dosing, minimising losses due to evaporation and surface runoff. For instance, for a 1 ha (10,000 m^2) field with a crop coefficient of 0.7, requiring evaporation and transpiration of 6 mm/day, and given a system efficiency of 0.9, the daily water consumption for drip irrigation can be calculated using the formula (1):

$$W_d = \frac{10000 \times 6 \times 0.7}{0.9} = 46.667.$$

Automatic irrigation systems are advanced technologies that have significantly changed the approach to water management in agriculture (Lopez-Jimenez *et al.*, 2022). Equipped with soil moisture sensors, rain sensors and data-driven control systems, these systems not only optimise the irrigation schedule but also significantly improve water use efficiency by avoiding over-watering or over-drying the soil.

Automatic irrigation, or sprinkler systems, have initial costs for sprinklers, pipework, pumps and control systems that can range from $2,000 to $5,000 per hectare. Operational costs include energy, equipment maintenance and regular inspections, at around $150-$400 per hectare per year. Moisture sensors placed in different parts of the field continuously collect data on soil conditions and transmit it to the control system. This allows the system to automatically adjust the watering schedule, providing plants with the right amount of moisture at the right time. This prevents situations where the soil remains too dry or too wet, which has a positive effect on plant health and yields. An additional advantage is the use of rain sensors that prevent watering during or immediately after rain. This not only prevents water overuse but also reduces the risk of waterlogging, which can lead to plant diseases and poor growth. Thanks to these sensors, automatic irrigation systems can significantly reduce water consumption, which is especially important in regions with limited water resources.

Modern data-driven management systems integrate information from a variety of sources, including meteorological data and weather forecasts. This improves watering plan accuracy, thus covering future weather conditions and plant needs. As a result, automatic irrigation systems become not just a tool for water supply, but a full-fledged part of the agricultural process management system, which significantly increases their efficiency. Modern automatic irrigation systems represent an important step forward in the field of water management in agriculture. They can significantly increase water use efficiency, improve plant health and increase yields, making them an integral part of sustainable and efficient agricultural production. In the context of global climate change and increasing water scarcity, such systems are becoming a key tool for ensuring food security and sustainable agricultural development. Automatic irrigation systems can be optimised with humidity and rain sensors. The optimal irrigation formula (2) assumes that with a maximum irrigation volume of 50,000 litres, 5 mm of precipitation and a threshold moisture level of 20 mm, the volume of water to be irrigated will be:

$$W_a = 50000 \times \left(1 - \frac{5}{20}\right) = 37.500.$$

In 2024, smart technologies and IoT have become an integral part of modern agriculture, opening new opportunities for efficient water management (Salam, 2024). The creation of integrated irrigation management systems based on data on weather conditions, soil conditions and plant needs can be used to automate the irrigation process, making it more accurate and efficient. Employing sensors installed in different parts of the field, IoT systems can monitor soil moisture levels, temperature, rainfall and other important parameters in real-time. This data is transferred to a central server where it is processed and analysed using specialised software. This can be used to create accurate models of field conditions and predict plant water requirements. Automation of the watering process based on collected data significantly increases its efficiency. Smart irrigation control systems can automatically adjust the water supply depending on current conditions and weather forecasts, which helps to avoid both overdrying and overwetting the soil. This not only improves plant health and yields but also significantly reduces water consumption, which is especially important in the face of global climate change and water scarcity.

The use of smart technologies and IoT in irrigation management systems can optimise the use of fertilisers and pesticides (Kumar *et al.*, 2022). In combination with precision irrigation, this ensures a more even distribution of nutrients and protective agents across the field, which improves their effectiveness and reduces the negative impact on the environment. Thus, the integration of smart technologies and IoT into agricultural processes contributes to the sustainable development of agriculture. The economic benefits of implementing smart irrigation management systems are also significant. Despite the initial costs of hardware and software, in the long term, such systems can significantly reduce water and labour costs. Automation of irrigation management processes frees farmers from the need for constant monitoring and manual adjustments, which increases overall productivity and reduces labour costs. However, despite the many benefits, the introduction of smart technologies and IoT in agriculture is fraught with challenges. This requires a significant initial investment and qualified personnel to install and maintain the equipment. It is also necessary to consider data security and protection to avoid potential cyber threats and unauthorised access to information.

The use of smart technologies and IoT in irrigation management systems represents an important step forward in the field of efficient water use and sustainable agriculture. These innovative solutions significantly increase the accuracy and efficiency of irrigation, improve plant health and yields, and reduce water and labour costs. In the context of global climate change and increasing water scarcity, smart irrigation management systems are becoming a key tool for ensuring food security and sustainable development of the agricultural sector. IoT can be used to control irrigation based on data about weather, soil conditions and plant needs. Formula (3) for determining water savings using IoT addresses the difference between the traditional watering volume of 50,000 litres and the IoT watering volume of 35,000 litres:

$$S_i = 50000 - 35000 = 15000.$$

The drip irrigation system is one of the most innovative and efficient irrigation technologies developed to optimise water use in agriculture (Wang & Guo, 2024). The main advantage of this system is the use of special devices that direct water directly to the root zone of plants. This minimises evaporation and surface run-off losses, providing plants with the right amount of moisture with maximum precision and efficiency. The main idea of the "spot irrigation" system is to deliver water precisely where it is most needed – to the roots of plants. Unlike traditional irrigation methods, such as surface or sprinkler irrigation, this system avoids excessive soil moisture and surface runoff, which often leads to soil erosion and loss of nutrients. Instead, the water is delivered through a network of tubes and emitters directly to the root zone, which ensures even moisture distribution and promotes healthy plant growth.

The effectiveness of the "spot irrigation" system has been confirmed by practical application in various climatic and soil conditions (Rocha *et al.*, 2023). It significantly reduces water consumption compared to traditional irrigation methods. This is especially important in regions with limited water resources or in drought conditions when water conservation becomes critical. In addition, drip irrigation helps to reduce plant disease, as it prevents water from reaching the leaves and stems, which reduces the risk of fungal infections and other diseases. In addition, the drip irrigation system improves product quality. Plants that receive the right amount of water in the root zone develop more evenly and healthily, which has a positive effect on the quality of fruits and vegetables. This is especially important for manufacturers focused on the fresh food market, where product quality and appearance play a key role.

Spot irrigation requires initial costs for spot irrigation and its installation, which range from $2,000 to $4,000 per hectare. Operating costs, including maintenance and energy, are around $100-$250 per hectare per year. Due to its economic and environmental efficiency, this system is becoming increasingly popular among farmers and agribusinesses seeking sustainable and highly productive agriculture. In the context of global climate change and growing water scarcity, the "point irrigation" system plays a key role in ensuring food security and sustainable development of the agricultural sector. These systems direct water directly to the roots of plants, minimising losses. Formula (4) for determining the efficiency of spot irrigation addresses the ratio of the volume of water used for spot irrigation (30,000 litres) to the traditional volume of irrigation (50,000 litres):

$$E_p = \frac{30000}{50000} = 0.6.$$

Water recycling and reuse systems are among the most significant innovations in agricultural water use (Chen *et al.*, 2021). These systems use treated wastewater or water from other secondary sources to irrigate crops. The main goal of such systems is to significantly reduce freshwater consumption, which is especially important in the context of global climate change and limited water resources. The use of recycled water in agriculture solves several key problems. Recycled water reduces freshwater usage, which is often under threat of depletion. In the face of drought and climate change, where freshwater resources are becoming scarce, water recycling is becoming vital to maintaining sustainable agricultural production. Using wastewater that has been properly treated helps to reduce environmental pollution and improve the quality of water resources in general. One of the most important aspects of water recycling systems is their environmental sustainability. The treated wastewater used for irrigation can contain certain nutrients, such as nitrogen and phosphorus, which can be beneficial for plants. This helps to reduce the use of chemical fertilisers, which in turn reduces the negative impact on soil and water bodies. Thus, water recycling systems contribute not only to saving water resources but also to improving the environmental situation in agricultural regions.

The practical application of such systems requires careful planning and management. The quality of the treated wastewater must meet certain standards to avoid harming plants and soil (Litynska *et al.*, 2023). This requires the installation of modern treatment facilities and regular monitoring of water quality. In addition, the specific needs of different crops and local climatic conditions must be addressed for optimal system performance. Examples of successful implementation of water recycling systems can be found globally. In Israel, for example, more than half of the water used in agriculture is recycled wastewater. This has allowed the country to achieve significant success in agriculture despite limited water resources. Israeli experience shows that proper management and investment in recycling technologies can ensure sustainable and efficient use of water resources (Onuh & Bassey, 2021).

Water recycling systems have initial costs for the installation of water recycling and treatment systems, which can range from \$3,000 to \$6,000 per hectare, and operating costs for system maintenance and water treatment are about \$200-\$500 per year per hectare. Water recycling and reuse systems represent an important step forward in sustainable water use in agriculture. These systems significantly reduce freshwater consumption, improve the environment and reduce water and fertiliser costs. In the context of global climate change and population growth, the need for such systems will only increase, making them a key element of sustainable agricultural development and food security. These systems use treated wastewater or water from other sources for irrigation. Formula (5) for determining freshwater savings addresses the difference between the traditional watering volume (50,000 litres) and the recycled water volume (40,000 litres):

$$S_w = 50000 - 40000 = 10000.$$

Agricultural drones are an advanced technology that significantly transforms the way agriculture monitors and manages irrigation (Thilagu & Jayasudha, 2022). These unmanned aerial vehicles can quickly and accurately collect data on the condition of fields, allowing farmers to make informed and timely decisions to optimise irrigation and increase yields. The DJI Agras T30 is an advanced agricultural drone that stands out for its technical characteristics (Fig. 1). Its design includes large rotors with a diameter of 2.5 metres and weighs about 18.1 kg unloaded, allowing the drone to effectively carry up to 30 kg of liquid or fertiliser. The maximum flight speed is up to 15 m/s, which enables fast processing of large areas. The drone is capable of processing up to 40 hectares on a single battery charge, depending on the density of the crop and the type of liquid.

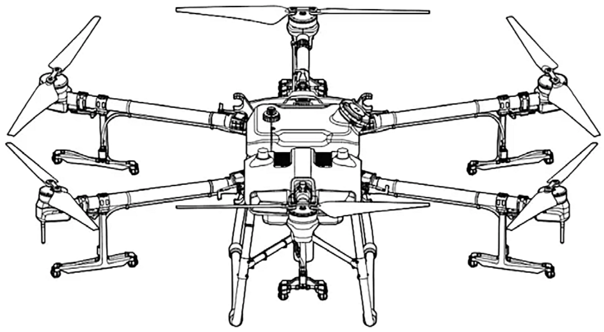

Figure 1. Diagram of the DJI Agras T30 drone
Source: Dji T30 Agras drone user manual (2022)

The T30 spray system is equipped with advanced technology that can adjust the volume and pressure of the spray, which ensures high precision in the application of fertilisers and pesticides. The flight time is up to 20 minutes on a single charge of the lithium-polymer battery, which can vary depending on the load and operating conditions. The drone is controlled by a specialised remote control and an integrated GPS, which allows for route planning and real-time flight monitoring. The DJI Agras T30 is equipped with safety features such as obstacle detection sensors and automatic landing in case of low battery or other malfunctions. In addition, the drone is waterproof and can be used in various weather conditions, including rain and fog (Seidaliyeva *et al.*, 2024). It can also be integrated with various sensors to monitor crop and environmental conditions, making it highly effective for agro-industrial monitoring and irrigation optimisation.

The main advantage of using drones in agriculture is their ability to conduct high-precision aerial photography and collect data on the condition of plants and soil over large areas. Equipped with a variety of sensors and cameras, drones can detect irrigation problems such as lack or excess of moisture, plant diseases and other factors affecting yields. This allows farmers to respond quickly to emerging problems and adjust irrigation regimes, which significantly increases the efficiency of water use. Drones also play a key role in assessing the effectiveness of irrigation methods. They can be used to regularly monitor field conditions and compare the results of different irrigation systems, such as drip irrigation, spot irrigation and automatic systems. This helps farmers identify the most effective methods and optimise their use to maximise yields and save resources. In addition, drones can collect data on soil moisture, plant health and other parameters, which can be used to create accurate field maps and develop individual irrigation strategies for different areas. Drones help reduce labour costs and increase productivity in agriculture. By automating the monitoring and data collection processes, farmers can reduce the amount of manual work and focus on making strategic decisions. This helps to improve labour organisation and increase the overall efficiency of agricultural enterprises. For instance, drones can replace workers who inspect fields, reducing the time and resources spent on these processes.

One of the most significant advantages of using drones is their ability to monitor fields in real-time. This is especially important in the face of unpredictable weather changes and other factors affecting the condition of fields and plants. Operational data obtained with the help of drones allows farmers to respond quickly to any changes and take measures to prevent crop losses. For example, drones can quickly detect drought or waterlogging in certain areas of fields, allowing farmers to adjust watering promptly and avoid plant damage. Agricultural drones are a powerful tool for monitoring and controlling irrigation, helping to improve the efficiency and sustainability of agriculture. Their ability to quickly and accurately collect data on the condition of fields and plants allows farmers to make informed decisions and optimise water use. In the context of global climate change and growing water scarcity, agricultural drones play a key role in ensuring sustainable agricultural development and food security. The use of drones requires significant upfront costs for the purchase of drones and data analysis software, which can range from $5,000 to $15,000 per drone. Operational costs include operator training, drone maintenance and data processing, which amount to around $1,000-$3,000 per year. Drones can monitor the condition of fields and assess the effectiveness of irrigation. Formula (6) for evaluating the efficiency of drone use addresses the ratio of the water volume when they are used (40,000 litres) to the maximum irrigation volume (50,000 litres):

$$E_d = \frac{40000}{50000} = 0.8.$$

Computer modelling and forecasting of plant water requirements are innovative approaches that significantly improve irrigation management in agriculture (Saggi & Jain, 2022). These technologies allow farmers to address many factors, such as soil type, climatic conditions and plant growth stage, to create optimal irrigation regimes. As a result, the use of such models contributes to efficient water use, increased yields and minimised environmental impact. The models can address soil characteristics such as permeability and retention capacity, as well as climatic data including temperature, humidity and precipitation. This allows farmers to plan irrigation activities, avoiding both water shortages and excesses that can negatively affect plant health and productivity. Accurate forecasts can also be used to adapt to weather changes and minimise the risks associated with extreme climatic conditions, such as droughts or heavy rain.

Computer modelling also contributes to the rational use of water resources, which is especially relevant in times of water scarcity. For instance, models can help determine the optimal watering intervals and volumes for different crops, which can reduce overall water consumption. This is especially important in arid regions where water resources are limited, as well as in the context of global climate change, which puts additional pressure on water supplies. Optimising irrigation using computer models helps to save water and increase the resilience of agriculture to changing conditions. Computer modelling also allows data from various sources to be integrated to create more accurate and comprehensive forecasts. For example, data from agricultural drones that collect information about the condition of fields can be used to improve models and increase their accuracy. This allows farmers to make more informed decisions and adapt their irrigation strategies to current field conditions. Modern models can also account for weather forecast data, which provides even more accurate irrigation planning and response to changing climatic conditions.

Computer modelling contributes to the sustainable development of agriculture by reducing the negative impact on the environment. Optimised irrigation minimises water run-off and the pollution of soil and water bodies by chemicals such as fertilisers and pesticides. This helps to improve the environmental situation and preserve biodiversity in agricultural areas. For example, models can help determine the optimal doses of fertilisers and pesticides, which reduces their overuse and pollution.

Computer models predict the water requirements of plants to optimise irrigation. Formula (7) for calculating the optimal watering volume using computer modelling is as follows: for a field of 1 ha (10,000 m²), with a crop coefficient of 0.8, evaporation and transpiration demand of 5 mm/day, and a model efficiency of 0.85:

$$W_c = 10000 \times 5 \times 0.8 \left(\frac{1}{0.85}\right) = 47059.$$

Modern irrigation systems offer many benefits that significantly improve agricultural efficiency and contribute to sustainable development (Table 1). The main ones include water savings, increased yields, reduced labour costs and environmental sustainability. Let us analyse these advantages in more detail.

Table 1. Comparative table of technical characteristics of irrigation systems

Irrigation system	Reduced water consumption	Increase in yields
Drip irrigation	Up to 50%	Up to 30%
Automatic irrigation systems	Up to 40%	Up to 20%
Use of smart technologies and IoT The “spot irrigation” system	Up to 60%	Up to 30%
Use of smart technologies and IoT	Up to 55%	Up to 25%
Water recycling and reuse systems	Up to 70%	Up to 15%
Agricultural drones	Up to 30%	Up to 10%
Computer modelling and forecasting	Up to 45%	Up to 20%

Source: compiled by the authors based on based on H. Veisi *et al.* (2022)

One of the most significant advantages of modern irrigation systems is water saving. Technologies such as drip irrigation and sensor-based automatic irrigation systems allow for precise distribution of water directly to the roots of plants. This reduces water loss through evaporation and surface runoff, which is especially relevant in regions with limited water resources. For instance, drip irrigation delivers water directly to the root zone of plants, minimising losses and ensuring that every litre of water is used more efficiently. Modern irrigation systems create optimum moisture conditions for plants, which contributes to their better growth and development. Precise dosing and even distribution of water ensures that plants receive the right amount of moisture at the right time in their life cycle. This leads to higher yields and improved product quality. For instance, the use of smart technologies and IoT makes it possible to create irrigation management systems that analyse data on weather conditions and soil conditions, ensuring timely and accurate irrigation.

Automation of watering processes significantly reduces the need for manual labour. Automatic irrigation systems can independently regulate the water supply depending on soil moisture, weather conditions and plant needs. This frees farmers from the need to constantly monitor the irrigation process and allows them to focus on other important aspects of farm management. For example, IoT-based automatic irrigation systems not only optimise the irrigation process but also allow agricultural enterprises to more accurately control water costs and reduce operating expenses. Modern irrigation systems contribute to the environmental sustainability of agriculture. Reduced water consumption and the use of treated wastewater for irrigation reduce the pressure on natural water resources. For instance, water recycling and reuse systems allow wastewater to be used for irrigation, which significantly reduces freshwater consumption. This is especially relevant in the context of global climate change when access to water resources is becoming increasingly limited. In addition, the rational use of water reduces the risk of soil and water pollution from chemicals such as fertilisers and pesticides, which helps to maintain the ecological balance.

In conclusion, modern irrigation systems are relevant for increasing the efficiency and sustainability of agriculture. Water savings, increased yields, reduced labour costs and environmental sustainability make these technologies indispensable in the face of global climate change and growing demand for food. Integrating advanced technologies into agricultural practices is a key step towards creating a more sustainable and productive agricultural sector.

DISCUSSION

Modern irrigation and watering systems are crucial in agriculture, providing optimal conditions for plant growth and development. These systems are aimed at solving one of the most pressing problems – the rational use of water resources. In the face of climate change and increasing water scarcity, the development and implementation of innovative irrigation methods are becoming vital. Modern technologies not only reduce water consumption but also significantly improve the efficiency of its use. This was also investigated by M. Attri *et al.* (2022), where the results confirmed that modern irrigation systems play a key role in agriculture aimed at optimal use of water resources. Traditional irrigation methods, such as surface watering or hand-held irrigation, are often characterised by low efficiency due to high water losses due to evaporation and discharge into groundwater. In comparison, modern irrigation technologies, such as drip irrigation and precision irrigation systems, can significantly reduce water consumption by distributing water resources more precisely and on target. This increases agricultural productivity while minimising water consumption and reducing the negative impact on the environment. S. Khriji *et al*. (2021) also showed that one of the main challenges of modern agriculture is water scarcity, exacerbated by climate change and increasing water stress. Innovative irrigation methods, such as aeroponics, hydroponics and precision irrigation systems, offer effective solutions for crop production in areas with limited access to water resources. Aeroponics and hydroponics are particularly important in the context of urbanised areas, where they reduce water consumption and optimise growing conditions. Precision irrigation technologies, such as soil moisture sensors and automated control systems, help to ensure that water is used precisely according to plant needs, which not only saves water but also increases yields and product quality (Atanasov, 2024). It is worth noting that these innovations not only improve the resilience of agriculture to changing climate conditions but also contribute to water conservation, which is critical for sustainable rural development and reducing water shortages.

One of the most promising technologies is drip irrigation, which delivers water directly to the roots of plants through a network of tubes, drippers and emitters. This precise water distribution minimises water losses due to evaporation and surface runoff, which is especially important in arid regions. Drip irrigation not only provides optimal conditions for plant growth but also helps to improve soil structure and prevent soil erosion (Shevchenko & Nikonchuk, 2022). As a result, this technology helps to increase yields and improve the quality of agricultural products. H. Wang *et al*. (2022) concluded that drip irrigation is an advanced irrigation technology that provides precise and targeted distribution of water directly to the roots of plants. This system can significantly improve the efficiency of water use in agriculture, as it minimises losses due to evaporation and runoff into the soil. Drip irrigation is especially effective in areas with uneven terrain or limited water supply, where it helps to save water and increase yields by more precisely controlling soil moisture and delivering the right amount of water and fertiliser directly to the plants. A. Patel *et al*. (2023) determined that in arid regions, drip irrigation plays a particularly important role in enabling agricultural enterprises to cope with limited access to water resources. Drip irrigation systems minimise water loss by directly delivering moisture to the roots of plants, which is especially important in conditions of high temperatures and intense evaporation. This not only saves water but also improves product quality thanks to a more consistent and controlled application of fertiliser and water to the soil. Thus, drip irrigation is an integral part of sustainable agriculture strategies in a changing climate, contributing to increased profitability and reduced environmental footprint of agricultural activities. These results confirm the above study, as they demonstrate a significant increase in yields and a reduction in water consumption due to the use of drip irrigation. Studies show that in regions with limited water resources, the use of drip irrigation can reduce water consumption for irrigation by up to 50% compared to traditional irrigation methods. This significantly reduces the ecological footprint of agriculture, reduces water extraction costs and helps prevent soil degradation by minimising erosion and salt deposits.

Automatic irrigation systems equipped with soil moisture sensors, rain sensors and data-driven control systems represent another important step in the development of modern irrigation methods. Such systems allow precise control of soil moisture levels and automatic adjustment of irrigation depending on current weather conditions and soil conditions. This helps to avoid waterlogging or overdrying, which can have a negative impact on plant growth. The introduction of automatic irrigation systems helps to significantly reduce labour costs and increase the overall efficiency of agricultural production. Notably, M. Pramanik *et al.* (2022) also determined that automatic irrigation systems are advanced technologies that allow precise control and maintenance of soil moisture depending on the needs of plants. These systems are equipped with soil moisture sensors and weather stations that automatically adjust the water supply according to the current environmental conditions and the growth stage of the plants. This approach avoids both moisture shortages and excesses, which contributes to the optimal development of the plant root system and increases yields. In addition, automatic irrigation systems significantly reduce the need for human intervention, which saves time and resources for agricultural enterprises. In turn, A. Jiménez *et al*. (2022) concluded that smart irrigation systems are high-tech solutions that include not only automated irrigation control but also data analytics to optimise agricultural processes. These systems use machine learning and artificial intelligence algorithms to predict plant water and fertiliser requirements based on historical data, weather conditions and current soil parameters. This approach significantly increases the efficiency of resource use, minimises losses and reduces the environmental footprint of agricultural operations. By integrating with modern management systems, smart irrigation systems not only improve product quality but also reduce operating costs and labour, making them an important element of sustainable and innovative agriculture. These data are consistent with the findings in the previous section, confirming that innovative approaches to irrigation management, such as automatic and intelligent irrigation systems, do indeed contribute to a significant increase in agricultural production efficiency. Automatic systems provide precise and timely soil moisture, which contributes to optimal plant growth and minimises inputs. Intelligent systems, in turn, not only automate the irrigation process but also predict the needs of plants, optimising the use of water and other resources based on sophisticated data and algorithms.

IoT and smart technologies are becoming increasingly popular in irrigation management (Nesterov, 2023). They are used to create integrated systems that analyse data on weather conditions, soil conditions and plant needs. These systems automate the watering process, making it more accurate and efficient. The use of IoT not only reduces water consumption but also improves field monitoring, which helps to detect problems promptly and resolve them quickly. As a result, such systems help to increase the resilience of agriculture to climate change. G. Gagliardi *et al*. (2021) also conducted a study that confirmed that the use of IoT in agriculture is a revolutionary approach to irrigation management based on real-time data collection and analysis. IoT systems include a network of sensors that continuously monitor soil parameters, humidity, weather conditions and other factors affecting plant growth. This data is transferred to specialised analysis platforms, enabling agricultural producers to make informed decisions on the optimal use of water resources and irrigation management. This approach not only increases irrigation efficiency by minimising water loss and improving yields but also reduces production costs and the ecological footprint of agriculture. Z. Ahmed *et al*. (2023) also determined that IoT and smart irrigation systems play a key role in making agriculture more resilient to climate change. With their help, agricultural enterprises can adapt to changing weather conditions, and predict and manage the risks associated with droughts or excessive moisture. Dynamic control of irrigation systems based on IoT data can be used to respond quickly to changes and optimise water consumption in real-time. In addition, such systems help to increase overall productivity and improve the quality of agricultural products, ensuring stable and efficient plant growth even in extreme climatic conditions. Based on the research findings, the use of IoT and smart technologies in agriculture not only improves traditional irrigation management methods but is also a key element in achieving long-term sustainability and dramatically reducing the environmental impact of agricultural activities.

The introduction of modern irrigation systems also has important environmental and socio-economic aspects. On the one hand, such technologies help to reduce the negative impact on the environment by reducing freshwater consumption and using resources more efficiently (Askar *et al*., 2023). On the other hand, they can significantly change the economic situation in agricultural regions. For instance, automation of irrigation processes can reduce operating costs and increase revenues for agricultural enterprises, which in turn has a positive impact on employment and income for residents. M. Mallareddy *et al*. (2023) concluded that modern irrigation systems, such as drip irrigation, and automatic and intelligent systems, play a key role in reducing water consumption in agriculture. Unlike traditional irrigation methods, which often lead to significant water losses due to evaporation and runoff into the soil, new technologies allow for more efficient distribution of water resources. Drip irrigation, for example, delivers water directly to the roots of plants, minimising losses and providing optimal conditions for their growth. This not only helps to save water but also reduces the negative impact on the environment by reducing soil degradation and salinity risks. F. Raza *et al*. (2022) determined that the introduction of innovative irrigation technologies has a significant socio-economic impact on agricultural regions. First, improved yields and quality of agricultural products have a favourable impact on farmers' incomes and regional economic development. Efficient use of water resources reduces irrigation costs and increases the competitiveness of agricultural products on the market. Study results analysis determined that innovative irrigation technologies not only contribute to environmental sustainability but also have a significant positive impact on the socio-economic development of agricultural regions, contributing to their sustainable and resilient development.

Despite the advantages, the introduction of modern irrigation systems faces several challenges. This includes the need for significant initial investment, technical difficulties associated with the installation and maintenance of equipment, and the need to train staff to work with new technologies. However, the prospects offered by these innovations for agriculture far outweigh the potential challenges. In the long term, modern irrigation systems can become a key element in the sustainable development of the agricultural sector, ensuring stable and high-quality food production even in the face of a changing climate and limited water resources.

CONCLUSIONS

The development of modern irrigation systems is a significant step in agriculture aimed at achieving several key goals: improving the efficiency of water use, reducing water consumption and increasing crop yields. Research in this area confirms that the introduction of modern technologies, such as drip irrigation, automatic irrigation systems, smart technologies based on IoT, spot irrigation systems and others, helps to optimise the use of water resources.

The analysis of the effectiveness of modern irrigation systems in different climatic and soil conditions is a key aspect of the study, showing that these systems can significantly reduce water losses due to their precise distribution to plant roots. This not only improves the conditions for plant growth and development but also makes efficient use of water resources, especially in conditions where access to water is limited and the climate is variable. Precise dosing of water directed to the roots of plants minimises evaporation and surface runoff, which increases irrigation efficiency and crop yields. The water savings achieved through such technologies play a key role in sustainable agriculture, enabling it to adapt to changing climate conditions and environmental challenges. Socio-economic analysis shows that the introduction of modern irrigation systems has a positive impact on agricultural regions. Automation of irrigation processes reduces operating costs and increases revenues for agricultural enterprises, which helps to improve the economic sustainability of regions and increase employment.

In general, the development and implementation of innovative irrigation and watering methods are essential for agriculture in the modern world. These technologies not only increase the productivity of the agricultural sector but also contribute to the sustainable use of natural resources, which is an important step towards ensuring food security and sustainable development of agricultural regions. The impact of modern irrigation and watering systems on biodiversity and ecological sustainability of agricultural ecosystems needs to be further studied. One of the limitations of this study is the limited availability of data on the long-term environmental and socio-economic impacts of modern irrigation systems.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Ahmed, Z., Gui, D., Murtaza, G., Yunfei, L., & Ali, S. (2023). An overview of smart irrigation management for improving water productivity under climate change in drylands. *Agronomy*, 13(8), article number 2113. doi: 10.3390/agronomy13082113.

[2] Askar, A., Sunggat, M., Maxat, M., Nunzhigit, S., Kanat, Z., Ainur, K., Arnay, A., & Asset, O. (2023). Investigation of the efficiency of the ozonator in the process of water purification based on the corona discharge. *Journal of Ecological Engineering*, 24(2), 140-151. doi: 10.12911/22998993/156610.

[3] Atanasov, S. (2024). Automated remote sensing system for crops monitoring and irrigation management, based on leaf color change and piecewise linear regression models for soil moisture content predicting. *Scientific Horizons*, 27(1), 127-139. doi: 10.48077/scihor1.2024.127.

[4] Attri, M., Bharti, V., Ahmad Nesar, N., Mehta, S., Bochalya, R.S., Kumar Bansal, K., & Sandhu, R. (2022). Improved irrigation practices for higher agricultural productivity: A review. *International Journal of Environment and Climate Change*, 12(9), 51-61. doi: 10.9734/ijecc/2022/v12i930737.

[5] Bansal, G., Mahajan, A., Verma, A., & Singh, D.B. (2021). A review on materialistic approach to drip irrigation system. *Materials Today: Proceedings*, 46(20), 10712-10717. doi: 10.1016/j.matpr.2021.01.546.

[6] Chen, C.Y., Wang, S.W., Kim, H., Pan, S.Y., Fan, C., & Lin, Y.J. (2021). Non-conventional water reuse in agriculture: A circular water economy. *Water Research*, 199, article number 117193. doi: 10.1016/j.watres.2021.117193.

[7] Curry, G.N., Nake, S., Koczberski, G., Oswald, M., Rafflegeau, S., Lummani, J., Peter, E., & Nailina, R. (2021). Disruptive innovation in agriculture: Socio-cultural factors in technology adoption in the developing world. *Journal of Rural Studies*, 88, 422-431. doi: 10.1016/j.jrurstud.2021.07.022.

[8] Dji T30 Agras drone user manual. (2022). Retrieved from https://manuals.plus/ru/dji/t30-agras-drone-manual.

[9] Dwijendra, N.K., Salih, M.S., Opulencia, M.J., Morozova, L., Sergushina, E.S., Asnan, M.N., Kadhim, M., & Kavitha, M. (2022). The effect of various irrigation technologies and strategies on water resources management. *Journal of Water and Land Development*, 53, 143-147. doi: 10.24425/jwld.2022.140790.

[10] Gagliardi, G., Lupia, M., Cario, G., Cicchello Gaccio, F., D'Angelo, V., Cosma, A.I., & Casavola, A. (2021). An internet of things solution for smart agriculture. *Agronomy*, 11(11), article number 2140. doi: 10.3390/agronomy11112140.

[11] Gómez, J., & Tascón, A. (2021). A protocol for using unmanned aerial vehicles to inspect agro-industrial buildings. *Informes de la Construcción*, 73(564), article number e421. doi: 10.3989/ic.84138.

[12] Hamdi, M., Rehman, A., Alghamdi, A., Nizamani, M.A., Missen, M.M., & Memon, M.A. (2021). Internet of Things (IoT) based water irrigation system. *International Journal of Online & Biomedical Engineering*, 17(5), 69-80. doi: 10.3991/ijoe.v17i05.22081.

[13] Jiménez, A.F., Cárdenas, P.F., & Jiménez, F. (2022). Intelligent IoT-multiagent precision irrigation approach for improving water use efficiency in irrigation systems at farm and district scales. *Computers and Electronics in Agriculture*, 192, article number 106635. doi: 10.1016/j.compag.2021.106635.

[14] Khriji, S., El Houssaini, D., Kammoun, I., & Kanoun, O. (2021). Precision irrigation: An IoT-enabled wireless sensor network for smart irrigation systems. In *Women in Precision Agriculture. Women in Engineering and Science* (pp. 107-129). Cham: Springer. doi: 10.1007/978-3-030-49244-1_6.

[15] Kumar, A., Ranjan, P., & Saini, V. (2022). Smart irrigation system using IoT. In *Agri-Food 4.0: Innovations, Challenges and Strategies* (pp. 123-139). Leeds: Emerald Publishing Limited. doi: 10.1108/S1877-636120220000027009.

[16] Litynska, M., Dontsova, T., & Gusak, A. (2023). Nanostructured iron-based sorption materials for drinking water and wastewater treatment. *Springer Proceedings in Physics*, 279, 243-255. doi: 10.1007/978-3-031-18096-5_13.

[17] Loiskandl, W., & Nolz, R. (2021). Requirements for sustainable irrigated agriculture. *Agronomy*, 11(2), article number 306. doi: 10.3390/agronomy11020306.

[18] Lopez-Jimenez, J., Vande Wouwer, A., & Quijano, N. (2022). Dynamic modeling of crop – soil systems to design monitoring and automatic irrigation processes: A review with worked examples. *Water*, 14(6), article number 889. doi: 10.3390/w14060889.

[19] Malhi, G.S., Kaur, M., & Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability*, 13(3), article number 1318. doi: 10.3390/su13031318.

[20] Mallareddy, M., Thirumalaikumar, R., Balasubramanian, P., Naseeruddin, R., Nithya, N., Mariadoss, A., Eazhilkrishna, N., Choudhary, A., Deiveegan, M., Subramanian, E., Padmaja, B., & Vijayakumar, S. (2023). Maximizing water use efficiency in rice farming: A comprehensive review of innovative irrigation management technologies. *Water*, 15(10), article number 1802. doi: 10.3390/w15101802.

[21] Naghdi, S., Bozorg-Haddad, O., Khorsandi, M., & Chu, X. (2021). Multi-objective optimization for allocation of surface water and groundwater resources. *Science of the Total Environment*, 776, article number 146026. doi: 10.1016/j.scitotenv.2021.146026.

[22] Nesterov, V. (2023). Integration of artificial intelligence technologies in data engineering: Challenges and prospects in the modern information environment. *Bulletin of Cherkasy State Technological University*, 28(4), 82-92. doi: 10.62660/2306-4412.4.2023.82-90.

[23] Onuh, P.A., & Bassey, U.I. (2021). Water resource management and sustainable development in Nigeria: Lessons from Israel. *University of Nigeria Journal of Political Economy*, 11, 48-68.

[24] Parada, F., Gabarrell, X., Rufí-Salís, M., Arcas-Pilz, V., Muñoz, P., & Villalba, G. (2021). Optimizing irrigation in urban agriculture for tomato crops in rooftop greenhouses. *Science of the Total Environment*, 794, article number 148689. doi: 10.1016/j.scitotenv.2021.148689.

[25] Patel, A., Kushwaha, N.L., Rajput, J., & Gautam, P.V. (2023). Advances in micro-irrigation practices for improving water use efficiency in dryland agriculture. In *Enhancing resilience of dryland agriculture under changing climate* (pp. 157-176). Singapore: Springer. doi: 10.1007/978-981-19-9159-2_10.

[26] Pramanik, M., Khanna, M., Singh, M., Singh, D.K., Sudhishri, S., Bhatia, A., & Ranjan, R. (2022). Automation of soil moisture sensor-based basin irrigation system. *Smart Agricultural Technology*, 2, article number 100032. doi: 10.1016/j.atech.2021.100032.

[27] Raza, F., Tamoor, M., Miran, S., Arif, W., Kiren, T., Amjad, W., Hussain, M., & Lee, G.H. (2022). The socio-economic impact of using Photovoltaic (PV) energy for high-efficiency irrigation systems: A case study. *Energies*, 15(3), article number 1198. doi: 10.3390/en15031198.

[28] Rocha, M.O., Cunha, F.F., Viana, F.J., & Oliveira, J.T. (2023). Classification and use of emitters used in spray irrigation systems. *Engenharia Agrícola*, 43(6), article number e20210183. doi: 10.1590/1809-4430-Eng.Agric.v43n6e20210183/2023.

[29] Saggi, M.K., & Jain, S. (2022). A survey towards decision support system on smart irrigation scheduling using machine learning approaches. *Archives of Computational Methods in Engineering*, 29(6), 4455-4478. doi: 10.1007/s11831-022-09746-3.

[30] Salam, A. (2024). Internet of things in water management and treatment. In *Internet of Things for sustainable community development* (pp. 273-298). Cham: Springer. doi: 10.1007/978-3-031-62162-8_9.

[31] Seidaliyeva, U., Ilipbayeva, L., Taissariyeva, K., Smailov, N., & Matson, E.T. (2024). Advances and challenges in drone detection and classification techniques: A state-of-the-art review. *Sensors*, 24(1), article number 125. doi: 10.3390/s24010125.

[32] Shevchenko, I., & Nikonchuk, N. (2022). Bioenergetic efficiency of drip irrigation modes of grapes. *Ukrainian Black Sea Region Agrarian Science*, 26(4), 73-81. doi: 10.56407/2313-092X/2022-26(4)-7.

[33] Sidhu, R.K., Kumar, R., Rana, P.S., & Jat, M.L. (2021). Automation in drip irrigation for enhancing water use efficiency in cereal systems of South Asia: Status and prospects. *Advances in Agronomy*, 167, 247-300. doi: 10.1016/bs.agron.2021.01.002.

[34] Thilagu, M., & Jayasudha, J. (2022). Artificial intelligence and internet of things enabled smart farming for sustainable development: The future of agriculture. In *Artificial intelligence and smart agriculture technology* (pp. 57-80). London: Auerbach Publications.

[35] Veisi, H., Deihimfard, R., Shahmohammadi, A., & Hydarzadeh, Y. (2022). Application of the analytic hierarchy process (AHP) in a multi-criteria selection of agricultural irrigation systems. *Agricultural Water Management*, 267, article number 107619. doi: 10.1016/j.agwat.2022.107619.

[36] Wang, H., Wang, N., Quan, H., Zhang, F., Fan, J., Feng, H., Cheng, M., Liao, Z., Wang, X., & Xiang, Y. (2022). Yield and water productivity of crops, vegetables and fruits under subsurface drip irrigation: A global meta-analysis. *Agricultural Water Management*, 269, article number 107645. doi: 10.1016/j.agwat.2022.107645.

[37] Wang, J., & Guo, Y. (2024). Analysis of sampling point irrigation area selection path for agricultural irrigation water consumption statistics. In *Proceedings of the 3rd international conference on public management and big data analysis*. Nanjing, People's Republic of China. doi: 10.4108/eai.15-12-2023.2345353.

[38] Zhang, W., Zhao, X., Gao, X., Liang, W., Li, J., & Zhang, B. (2024). *Spatially explicit assessment of water scarcity and potential mitigating solutions in a large water-limited basin: The Yellow River basin in China*. Preprint. doi: 10.5194/hess-2024-88.

Бакитбек Аскаралієв
Кандидат технічних наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0002-7180-2671
Касієт Мусабаєва
Кандидат історичних наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0002-9145-9866
Бараталі Кошматов
Кандидат технічних наук, в.о. професора
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0003-1601-1284
Канат Омурзаков
Аспірант, старший викладач
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0001-8654-3767
Жипаркул Джакшиликова
Аспірант, старший викладач
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0009-0007-5259-3054

Розвиток сучасних систем поливу та зрошення спрямований на підвищення ефективності, зменшення споживання води та збільшення врожайності

Анотація. Дослідження було проведене для вивчення сучасних систем поливу та зрошення, спрямованих на підвищення ефективності використання води, зниження її споживання та збільшення врожайності сільськогосподарських культур. У рамках дослідження було проаналізовано екологічні та соціально-економічні аспекти застосування сучасних систем поливу та зрошення, включно з їхнім впливом на навколишнє середовище та соціальну стійкість сільського господарства. У дослідженні було встановлено, що використання сучасних систем поливу та зрошення, як-от крапельне зрошення та автоматичні системи управління на основі IoT, дає змогу значно підвищити ефективність використання води в сільському господарстві. Аналіз даних показав, що такі системи можуть знизити споживання води до 50 %, при цьому збільшуючи врожайність до 30 %. Використання агропромислових дронів для моніторингу стану полів і точного регулювання поливу сприяє поліпшенню здоров'я рослин і зниженню витрат на працю. Також було виявлено, що системи рециркуляції та повторного використання води можуть суттєво зменшити використання прісної води, що особливо важливо в регіонах з обмеженими водними ресурсами. Загалом, сучасні технології зрошення демонструють високу ефективність та економічну доцільність, сприяючи сталому розвитку сільського господарства. Було доведено, що застосування комп'ютерного моделювання та прогнозування потреб рослин у воді забезпечує оптимальні умови для їхнього росту, що додатково сприяє збільшенню врожайності. Результати дослідження можна використовувати на практиці для розроблення та впровадження більш ефективних та екологічно чистих технологій у системах зрошення та водовідведення, що сприяє зниженню негативного впливу на навколишнє середовище за рахунок більш раціонального використання водних ресурсів та скорочення водних стоків

Ключові слова: агропромислові дрони; комп'ютерне моделювання; прогнозування потреб рослин; оптимальні умови для росту; водокористування