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USE OF INNOVATIVE IRRIGATION TECHNOLOGIES TO IMPROVE THE EFFICIENCY OF AGRICULTURAL PRODUCTION

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ВИКОРИСТАННЯ ІННОВАЦІЙНИХ ТЕХНОЛОГІЙ ЗРОШЕННЯ ДЛЯ ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ АГРАРНОГО ВИРОБНИЦТВА

The article discusses the feasibility of widespread practical application of innovative, resource-saving technologies in crop irrigation systems. In Ukraine, the current water management policy in the agricultural sector needs to be reviewed and amended. This is due to the fact that the process of adapting agricultural management in our country to economic and climate change is difficult. As a result, there are numerous shortcomings in the management and supervision of the water use sector, and water users, in turn, are not interested in the efficient and rational use of irrigation water. In addition, the deteriorating technical condition of hydraulic structures and networks has rendered many irrigated areas inoperable and unusable. Problems arising in the field of water management reduce the competitiveness of agricultural products and lead to higher crop production costs. Therefore, the issue of efficient and rational use of land and water resources has been identified as an important problem for the country's current socio-economic development. This is due to the fact that the food security of any state and the standard of living of its population are directly related to these factors. To solve this problem, it was proposed to maximise the use of the main available resources, namely land and water, with maximum productivity and efficiency, to expand irrigated areas in agriculture and to conserve irrigation water. In order to analyse the factors that influence the performance of the irrigation system as a whole, a comparative analysis of the effectiveness of different irrigation methods was carried out. It is established that the use of drip irrigation with mulching provides an increase in crop yields by 21—31% compared to traditional irrigation while reducing water consumption by 40—50%. The role of water user organisations as a key institutional mechanism for reforming the reclamation industry and attracting investment in the modernisation of irrigation infrastructure is substantiated. The priority directions of the state policy on the introduction of water and energy-saving technologies in agricultural production in Ukraine are determined.

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У статті розглядається доцільність широкого практичного застосування інноваційних, ресурсозберігаючих технологій в системах зрошення сільськогосподарських культур. В Україні поточна політика управління водними ресурсами в сільськогосподарському секторі потребує перегляду та внесення змін. Це пов'язано з тим, що процес адаптації сільськогосподарського управління в нашій країні до економічних і кліматичних змін проходить з труднощами. Як наслідок, існують численні недоліки в управлінні та нагляді за сектором водокористування, а водокористувачі, в свою чергу, не зацікавлені в ефективному та раціональному використанні зрошувальної води. Крім того, погіршення технічного стану гідротехнічних споруд і мереж призвело до того, що багато зрошуваних площ стали непрацездатними і непридатними для використання. Проблеми, що виникають у сфері управління водними ресурсами, знижують конкурентоспроможність сільськогосподарської продукції та призводять до підвищення витрат на виробництво сільськогосподарських культур. Тому питання ефективного та раціонального використання земельних і водних ресурсів визначено як важливу проблему для сучасного соціально-економічного розвитку країни. Це пов'язано з тим, що продовольча безпека будь-якої держави та рівень життя її населення безпосередньо пов'язані з цими факторами. Для вирішення цієї проблеми було запропоновано максимально використовувати основні наявні ресурси, а саме землю та воду, з максимальною продуктивністю та ефективністю, розширити зрошувані площі в сільському господарстві та зберегти зрошувальну воду. З метою аналізу факторів, що впливають на показники ефективності іригаційної системи в цілому, було проведено порівняльний аналіз ефективності різних методів зрошення. Встановлено, що застосування крапельного зрошення з мульчуванням забезпечує підвищення врожайності сільськогосподарських культур на 21—31% порівняно з традиційним поливом при одночасному скороченні витрат води на 40—50%. Обгрунтовано роль організацій водокористувачів як ключового інституційного механізму реформування меліоративної галузі та залучення інвестицій у модернізацію зрошувальної інфраструктури. Визначено пріоритетні напрями державної політики щодо впровадження водо- та енергоощадних технологій в аграрному виробництві України.

Key words: irrigated lands, innovative technologies, water conservation, economic efficiency, drip irrigation, sprinkler irrigation, water user organisations, reclamation systems.

Ключові слова: зрошувані землі, інноваційні технології, збереження води, економічна ефективність, крапельне зрошення, дощувальне зрошення, організації водокористувачів, меліоративні системи.

INTRODUCTION

The main goal of Ukraine's agricultural policy today is to meet the demand for raw materials for food and processing enterprises in the country. Therefore, it is necessary to create an efficient agricultural production system that will meet the country's food needs and develop the agricultural sector through the efficient use of irrigated agriculture. For Ukraine, ensuring a guaranteed harvest has always been an important issue. Agriculture is the country's main resource. However, its potential is not fully utilised. There is a need to effectively use existing hydromelioration measures and increase the area of irrigated land. These measures, in turn, will increase agricultural production [1].

In many regions of Ukraine, the natural amount and distribution of precipitation is insufficient to ensure stable crop yields. Experts estimate that a significant portion of arable land requires irrigation, while the actual area under irrigation remains limited. The lack of efficient irrigation systems leads to significant economic losses: in southern Ukraine alone, they are estimated at around USD 300 million annually [2].

Due to its natural and climatic conditions, Ukraine is one of the countries where hydraulic reclamation, in particular irrigation, plays a crucial role in ensuring sustainable crop production. Ukraine's territory covers 60.3 million hectares, of which 41.4 million hectares are farmland. At the same time, Ukraine has a unique soil cover: more than 60 per cent of its area is covered by chernozem soils, which are characterised by a high level of fertility [3].

Climate change poses additional threats to the country's food security due to the growing deficit of the annual water balance in a large part of the territory, the deterioration of the engineering infrastructure of reclamation systems, and the stagnation of irrigation potential. The use of the irrigation systems' potential is currently extremely unsatisfactory, as only about 137,000 hectares of the available 2.2 million hectares of irrigated land are actually irrigated, and thus reclaimed land has lost its ability to serve as an insurance fund for the

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state's resource and food supply in years with adverse weather conditions. Studies have shown that in the medium and long term, there is a high probability of an increase in the area of arable land with insufficient moisture to 20.6 million hectares (67 per cent) and 24.9 million hectares (80 per cent), respectively, and by 2050, about half of the arable land in Ukraine will be unsuitable for farming without irrigation [3].

One of the main reasons for the low efficiency of water use is that in the water sector, instead of demand regulation, the emphasis was exclusively on the expansion of water infrastructure as a mechanism for resource allocation, which led to the extensive development of water infrastructure.

THE REVIEW OF THE LITERATURE

In agriculture, the issues of water use efficiency for irrigation, increasing the productivity of reclaimed land, and applying innovations and technologies were studied by domestic scientists M.I. Romashchenko, S.O. Balyuk and others, and A.O. Gutorov [4, 5, 6]. They devoted their works to the study of the problems of irrigated agriculture development and introduction of innovative technologies. Similarly, within the framework of the adopted economic management system, each state determines measures related to the use of its water resources and the conservation of irrigation water in accordance with its own laws and programmes.

The legal framework for the functioning of water user organisations is defined by the Law of Ukraine "On Water User Organisations and Stimulation of Hydraulic Land Reclamation" No. 2079-IX dated 17 February 2022. The strategic guidelines for the development of the industry are outlined in the Irrigation and Drainage Strategy in Ukraine for the period up to 2030, the Water Strategy of Ukraine for the period up to 2050, and the Long-term Plan for the Development of the Irrigation Complex of Ukraine until 2050, approved by the Cabinet of Ministers of Ukraine on 25 March 2025, No. 280-p [3, 7].

Therefore, effective management of land and water resources, implementation of measures to save water in irrigation in conditions of water shortage and introduction of innovative technologies in agriculture should be the main priority of the state today. The above-mentioned issues are the basis for the research in this article.

The purpose of the article. The purpose of the article is to substantiate the feasibility of widespread practical application of innovative resource-saving technologies in crop irrigation systems in Ukraine. The methodological basis of the study is the scientific works of domestic and foreign economists on irrigated agriculture and innovative water-saving technologies. In addition, the methods of systematic logical research, such as comparative and economic-mathematical analysis, forecasting and data processing, were applied.

RESEARCH RESULTS

One of the main ways to improve the efficiency of irrigated land in agriculture is to introduce new scientific achievements to save water and improve the land reclamation status, i.e. innovative methods of crop irrigation. Currently, irrigation infrastructure is installed on a total area of 2.2 million hectares of irrigated land in agriculture, but modern drip and sprinkler irrigation technologies are used only on a small part of this area [3].

The engineering infrastructure of the irrigation complex, built in the 60s and 80s of the last century, as of 1990, provided irrigation for the entire area of irrigated land — 2.20 million hectares. At the same time, 6813 million cubic metres (27.35 per cent) of the total fresh surface water intake was used for irrigation purposes. Due to Ukraine's transition to a market economy, denationalisation and privatisation, land parceling, and the transfer of on-farm reclamation systems to communal ownership, the area of actual irrigated agricultural land has significantly decreased. According to an inventory conducted in 2013, 614 thousand hectares (28 per cent of the total area of irrigated land) were irrigated [3].

After the occupation of the Autonomous Republic of Crimea and parts of Donetsk and Luhansk regions in 2014, as well as the beginning of the full-scale invasion in 2022, the occupation of parts of Kherson and Zaporizhzhia regions and the destruction of the Kakhovka reservoir, which was a source of irrigation for the south of the country, the actual area of irrigated land decreased to 136,000 hectares in 2023. The undermining of the Kakhovka Reservoir dam by Russian forces left 94 per cent of irrigation systems in Kherson region, 74 per cent in Zaporizhzhia region and 30 per cent in Dnipro region without a source of irrigation for a long time. According to an official World Bank report, the total cost of damage to Ukraine's irrigation and water resources sector is estimated at USD 746.3 million, and the amount of funds needed to restore the sector is USD 10,936 million [3, 8].

A number of measures need to be taken to address the problem of efficient use of water resources in agriculture, namely

— expanding the area of irrigated land and improving its quality;

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— reducing water consumption by improving the irrigation of crop varieties grown on irrigated lands, increasing the use of drought-resistant crop varieties and optimising water use efficiency through the effective application of irrigation technologies;

— improving innovative and efficient irrigation technologies in agriculture;

— improving the skills of specialists and farmers in the field of hydromelioration;

— influence on farms by stimulating water saving measures in water use, etc.

Irrigation is a key factor in intensifying agriculture in areas of insufficient moisture. Irrigation equipment must ensure the supply of water to the field, its distribution and transformation into a form available to plants (rain, surface flow, drops). The most common method of mechanised irrigation is sprinkling, which imitates natural rain [9].

To create artificial rain, sprinkler nozzles and devices are used, which are divided into short-jet (up to 5—8 m), medium-jet (15—35 m) and long-jet (40—80 m) according to the range of drops. Long-range sprinklers usually operate on the principle of barrel rotation under the influence of the jet force of the water jet or special turbines and rockers.

Among the widely used sprinklers, it is worth highlighting the two-cantilever sprinkler unit DDA-100MA. This unit is mounted on a tractor (e.g. DT-75M or A-90) and is designed to irrigate crops while driving along an open sprinkler. Water intake is carried out by a centrifugal pump mounted on the machine frame, and distribution is carried out through a truss pipe system with short-jet nozzles. The working width of the unit is 120 metres [9].

For automated irrigation of large areas, the Fregat multi-pillar sprinkler machine (DMu) is widely used, which operates in a circular motion. The machine consists of a fixed central support, to which water is supplied under pressure, and a water supply pipeline supported by a series of self-propelled trolleys. The design is unique in that it uses a hydraulic drive for the trolleys' running systems, which is powered by the energy of the water supplied for irrigation. The hydraulic cylinders drive the wheels of the supports through a system of levers and pushers. The automatic motion synchronisation system ensures that the pipeline is aligned in a line by adjusting the speed of the intermediate trolleys relative to the last one, which sets the pace [9].

An important aspect of sprinklers' operation is compliance with the operating pressure, which affects the quality of spraying, irrigation rate and uniformity of moisture distribution. Modern irrigation systems also include pumping stations (stationary and mobile), which ensure that water is taken from the source and supplied to the irrigation network at the required pressure. A promising area is the development of pulse and drip irrigation systems, which can significantly save water resources and supply water directly to the root zone of plants, which is especially important for perennial plantations and vegetable crops [9].

In practice, modern irrigation and land reclamation systems use a variety of innovative technologies, including micro-irrigation, drip and pulse irrigation, as well as various methods of supplying water to plants by spraying soil and leaves.

Micro-irrigation (sprinkling) is a method of supplying water to crops, in which irrigation water is applied to the surface of the soil and plants using special spray equipment that simulates artificial rain. In this case, the water not only increases soil moisture but also humidifies the surface air layer, thereby reducing its temperature. In addition, sprinkler irrigation helps to wash away dust from plants, which improves their breathing and promotes the development and accumulation of organic matter. No small channels or ruts are formed after irrigation, so the land can be fully utilised and agricultural machinery can operate efficiently.

Compared to other types of surface irrigation, drip irrigation has several advantages, namely

— mechanisation of labour processes;

— simultaneous germination and development of seedlings in the soil;

— the ability to plan the exact amount of irrigation water according to the stage of crop development and soil conditions;

— due to the economical use of irrigation water, the efficiency of its use increases by 25—30%, etc.

According to scientific studies, fine spraying on tea plantations reduces the air temperature on the surface by 6—10 degrees, increases the relative humidity of the crown by 25—37% and increases the yield by up to 4.33 tonnes per hectare [10].

However, when drip irrigation is used to cultivate large areas in windy conditions, this method can lead to uneven distribution of moisture in the soil and overestimation of irrigation rates. At the same time, the high frequency of irrigation has also been identified as one of its main disadvantages.

When using an underground irrigation system, water is supplied directly from a certain depth to

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Table 1: Dynamics of the area of actually irrigated agricultural land in Ukraine in 2020—2024, thousand ha

Year	Actually irrigated area, thousand ha	Change year-on-year, thou hectares	Rate of change, %.
2020	551	-	-
2021	525	-26	95,3
2022	308	-217	58,7
2023	136	-172	44,2
2024	137	+1	100,7

Source: compiled based on [3].

the root zone of the soil. The water is supplied through cracks and holes in the pipes. The underground irrigation system prevents soil erosion and saves 55—60% of irrigation water compared to the furrow irrigation method.

The next method of drip irrigation is a technique of supplying water directly to the roots of crops through special microtubes with minimal water loss. It maintains an optimal level of soil moisture during the growing season. Due to the small volumes (0.9—9.1 litres per hour), irrigation water is supplied slowly, drop by drop, into the soil, moistening only the root zone. Drip irrigation is widely used for growing vegetable and fruit crops both indoors and outdoors.

Advantages of drip irrigation:

— In agricultural irrigation, compared to traditional methods, certain water savings (50-80%);

— no surface water flow and soil erosion;

— reduction in the number of pests and plant diseases;

— efficient and rational use of the root zone at the stages of germination and development of crops;

— the possibility of using fertilisers with irrigation water;

— eliminating the threat of groundwater depletion and reducing the risk of soil salinisation, etc.

In practice, drip irrigation increases the efficiency of mineral fertilisers by 30%, saves water per hectare by 40—50%, and reduces fuel consumption by 60%.

Disadvantages of drip irrigation:

— high cost;

— the need to install special filters for water purification;

— the need to rebuild the irrigation system when distributing water across fields, etc.

Globally, the area of agricultural land irrigated with drip irrigation is growing due to its high economic efficiency. Over the past twenty years, the area has increased six and a half times, reaching 10.3 million hectares in 2020. Micro-irrigation systems are being intensively implemented in the regions of China and India. Here, over the past twenty years, the area has increased by 88 and 112 times, respectively [11].

Currently, many countries have begun to use an innovative method of mulching with plastic film for drip irrigation. Mulching is the placement of a protective layer of any material on the soil surface to protect it from excessive weed growth, soil crusting and imbalance between water and air.

Features of the film mulching method for drip irrigation:

— soil temperature at a depth of 5 cm can be increased by 7—9 degrees;

— soil compaction is reduced;

— root growth and oxygen exchange (soil aeration) are improved;

— the number of weeds and the likelihood of their occurrence are significantly reduced;

— mulching with black polymer film allows harvesting 14 days earlier.

Work is also underway to introduce innovative irrigation technologies in Ukraine. It is worth noting that this is done to save precious irrigation water. The dynamics of the area of actually irrigated agricultural land in Ukraine is shown in Table 1.

According to Table 1, in 2020—2021, the area of actually irrigated land in Ukraine remained relatively stable and amounted to about 550 thousand hectares. Starting in 2022, there was a downward trend in the irrigated area, and in 2023 there was a sharp decline to about 136 thousand hectares. In 2024, there was a slight increase in the area of irrigated land to about 137 thousand hectares, indicating a gradual resumption of operation of some irrigation systems.

The main reasons for this decrease were military operations on the territory of Ukraine, the occupation of parts of the southern regions, which traditionally have the largest areas of irrigated agriculture, and the destruction of important water infrastructure facilities, including the Kakhovka hydroelectric power plant. This led to the disruption of the functioning of the North Crimean and Kakhovka main canals, which supplied water to large areas of agricultural land. In addition, the deterioration of reclamation systems, insufficient funding for their modernisation, and significant water losses during transportation had a negative impact.

At the same time, the situation can be gradually stabilised through the development of modern water-saving irrigation technologies, including drip and local irrigation, which can significantly

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reduce water consumption and increase the efficiency of land use. Another important area is the restoration and modernisation of existing reclamation systems, reconstruction of damaged hydraulic infrastructure, introduction of innovative water management systems and attraction of state and international investments in the development of irrigated agriculture.

In order to save water for irrigation and increase yields, the mulching method was applied together with drip irrigation and compared with other irrigation methods. It is noteworthy that when using innovative irrigation methods, the yield compared to traditional flood irrigation increases by 21.4% with drip irrigation and by 31.2% with drip irrigation with mulching. Similarly, for potato irrigation, these figures are 18.1% and 31.6%, respectively. In addition, these innovative irrigation methods control the soil moisture regime. The ability to change the processes of plant growth and development as needed reduces the dependence of agriculture on natural climate change.

In addition to increasing productivity, the drip irrigation system with mulching prevents soil erosion, ensures even distribution of water and regulates the ripening time of crops. The result is a reduction in crop ripening time (e.g. 12—15 days for cotton), the ability to automate the irrigation process, increased labour productivity, improved land use and efficiency of the irrigation system. In addition, the simultaneous application of mineral fertilisers using drip irrigation systems, i.e. fertigation, allows for optimal and even maintenance of the soil's water-air regime, and balanced application of nitrogen, phosphorus, potassium and other nutrients, taking into account the stages of crop growth and seasonal needs.

The above analysis shows that innovative technologies not only increase productivity, but also reduce heavy manual labour and associated costs, which leads to significant resource savings. Its importance is growing at a time when preserving the environment and improving its ecological condition are pressing issues. In the first year of application of the innovative technology, the system is cost-effective in the production of crops such as corn, sunflower and wheat.

Increasing the efficiency of irrigated land use is directly related to the intensity of agricultural production, as described above, and to the increase in the coefficients of efficient use of irrigation water. Therefore, the widespread use of innovative and resource-saving technologies in crop irrigation systems is the basis for increasing the efficiency of irrigated land.

An important area of reclamation sector reform is the creation of water user organisations (WUOs). The Law of Ukraine "On Water User Organisations and Stimulation of Hydraulic Land Reclamation" introduced a new organisational and legal form of management of reclamation systems for the first time. A water user organisation is created for the effective implementation of hydrotechnical land reclamation on agricultural land plots included in the organisation's service area [7].

As of December 2025, 71 water user organisations were registered in Ukraine in 14 regions (Vinnytsia, Volyn, Dnipro, Zhytomyr, Kyiv, Kirovohrad, Mykolaiv, Odesa, Poltava, Kharkiv, Kherson, Cherkasy, and Chernihiv), uniting more than 150 agricultural producers. The leaders in terms of the number of established WUCs are Cherkasy (17) and Odesa (12). Water users' organisations are being actively created both on irrigation systems (52 WUCs) and on drainage systems (10 WUCs). As of the beginning of 2025, the total polygonal area of the WUC territories is 36.5 thousand hectares [12].

During 2023—2025, the State Agency for Fisheries ensured the transfer of the engineering infrastructure of reclamation networks to four water user organisations — Voda Zhyttia, Shchedra Zemlya, Kvituchi Lany and Persha Kiliyska. This allows land users to fully manage the transferred facilities, as well as to attract investments and grants by introducing new energy and water-saving technologies [12].

According to the Long-Term Plan for the Development of the Irrigation Complex of Ukraine until 2050, at least 95 per cent of the hydromelioration property should be transferred to the ownership of water user organisations (except for privately owned facilities and canals of national importance) by 2030, and the number of WUCs is planned to increase to 110. Implementation of the plan envisages an increase in the area of irrigated agricultural land to 235,000 hectares by 2030 and to 700—750,000 hectares by 2050 [3].

According to the Long-Term Plan for the Development of the Irrigation Complex of Ukraine, the main areas of restoration of irrigation systems, their modernisation and reconstruction in the context of climate change are

— application of low-pressure sprinkler systems with electric trolley drive, drip irrigation systems (reduction of irrigation water and electricity consumption for its supply by up to 20 per cent);

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— modernisation and reconstruction of pumping stations with replacement with high-efficiency units with soft start and adjustable capacity, installation of automation control systems for pumping stations (reduction of electricity consumption by up to 25 per cent);

— use of closed-type networks for water supply, mainly using polymer pipes and daily regulation pools — storage ponds (reduction of irrigation water losses due to evaporation, increase in the area irrigated by pumping stations);

— Implementation of anti-filtration measures in canals and storage ponds (reduction of infiltration losses of irrigation water from canals by up to 80 per cent);

— use of alternative and renewable energy sources;

— equipping irrigation systems with the means of preparing and applying ameliorants, fertilisers, microelements, pest and weed control agents together with irrigation water [3].

The implementation of these measures will result in a reduction in the use of irrigation water and electricity for its supply by up to 20 per cent, an increase in crop yields by up to 20 per cent, and savings in fertilisers and plant protection systems by up to 15 per cent [3].

CONCLUSIONS

Thus, the issues discussed above reflect the current state of the water sector, its current structure and composition, as well as the industry players. Clarification and optimisation of the status of hydromelioration systems and water management facilities, as well as the tasks of the sector's actors, taking into account the practice of developed countries, requires the development of measures that ensure effective management of the water sector and rational use of water resources. The results of the research have shown that the introduction of innovative irrigation technologies is one of the most pressing and urgent issues. This is due to the fact that their implementation in practice can increase the economic efficiency of irrigated land in agriculture and save 40-50% of irrigation water.

To increase the efficiency of irrigation water use in agriculture, maintain existing water management and irrigation systems in working order, it is necessary to ensure the preservation of reclamation systems, overhaul hydraulic structures, ensure the effective use of agricultural hydromelioration measures at the local level, and introduce innovative water and energy saving technologies.

Thus, the use of resource-saving innovative technologies in crop irrigation has a high potential to increase the efficiency of irrigated land and improve the land reclamation status.

For large-scale implementation of drip irrigation systems on agricultural land in Ukraine, it is necessary to

— Establish an effective crop rotation for drip irrigated crops;

— organise the supply of equipment for drip irrigation systems;

— provide advice to farmers on drip irrigation methods;

— stimulate the use of drip irrigation methods in agriculture and intensively carry out other related work.

In our opinion, the state should perform its function as the main regulator in the system of land and water relations. First of all, this concerns the improvement of agricultural production in combination with scientific, innovative and technological processes to support and intensify irrigated agriculture. At the same time, it is important to give priority to water-saving, soil-saving and environmentally friendly technologies in agricultural production based on the experience of developed countries. In addition, there is a need to improve state mechanisms for controlling and regulating agribusiness in the country, as well as to accelerate financial support for the introduction of innovative crop production technologies. An equally important area is to promote the creation of water user organisations and the transfer of reclamation infrastructure to them, which will ensure decentralisation of irrigation system management and attract private investment in their modernisation.

Prospects for further research include studying the economic efficiency of different types of innovative irrigation technologies for specific crops in different climatic zones of Ukraine, as well as developing mechanisms for attracting private investment in the modernisation of reclamation infrastructure through water user organisations.

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