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REDUCING OF WATER AND ENERGY RESOURCES CONSUMPTION IN IRRIGATION BASED ON RESOURCE OPTIMISATION

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Abstract. *The need for further development of irrigation practices on the basis of nature oriented and ecologically efficient solutions is considered primarily regarding the saving of water and energy resources for the adaptation of irrigated agricultural production to the current global challenges and threats, the achievement of sustainable development goals. It is shown that there is an objective need to change methodological approaches to the assessment of overall efficiency and justification of optimal solutions in design, reconstruction, and operation projects of irrigation systems based on the principles of resource optimization. On the basis of the indicator of the level of irrigation sufficiency (introduced by the authors), which reflects the reduction of the studied watering and irrigation rates in relation to their design values, a study of the impact of reducing the use of water and energy resources under different modes of sprinkler irrigation on the corresponding decrease in the level of cultivated crops productivity was carried out. At the same time, it was experimentally determined that the intensity (rate) of the decrease in the cultivated crops productivity, which occurs due to the decrease in the usage of water and energy resources during the application of irrigation, is significantly lower than the intensity (rate) of the decrease in the usage of the resources themselves. The studied options for reducing the consumption on water and energy resources as a whole turned out to be economically profitable when with a decrease in water and electricity usage by 27–48 % there is more than two times lower decrease in the costs of gross products by 10,80–18,06 % with the achievement of a net income of 11,4 to 5,7 thousand UAH. The influence of various options of reducing water and electricity consumption on the discounted investment payback period shows that several options may be acceptable, for which the investment payback period does not exceed 10 years, and the choice of the optimal solution requires taking into account the conditions of a specific object, limitations of water resources, and the interests of investors and land users. At the same time, the ecological component of the overall efficiency of irrigation practices consists in the decrease in the use of water and energy resources that a priori reflects the decrease in the negative impact of irrigation on the environment. Thus, reducing the usage of water and energy resources is a fully justified decision on the way to adapt irrigated agriculture production to the modern conditions and requirements, and the presented results can be a scientific basis for the implementation of this approach while practically applying irrigation.*

Key words: *consumption reduction, water resources, energy resources, irrigation, resource-based optimization*

Relevance of research. Existing global problems related to climate changes, food, water, and energy crises confront the world community, including Ukraine, with the need to adapt to existing challenges and threats and to increase the overall efficiency of all sectors of economy, primarily agricultural production, in order to achieve the goals of sustainable development as the main modern concept of the further development of society with the aim of the safety for future generations, in particular, regarding the need for a safe and healthy environment [1–4].

The major part of territory of our country, and, accordingly, agricultural lands, are traditionally located in the zone of risky agriculture with insufficient level of natural moisture, and therefore their use for crop growing requires irrigation to a greater or lesser extent. In addition, in recent years, as a result of climate changes, the zone of risky agriculture in Ukraine has significantly expanded and, according to various estimates of scientists, reaches 18–20 million hectares [5]. At the same time, irrigated lands were, are, and remain a valuable production resource, which make it possible to obtain 2-3 times larger volumes of crop production compared to rainfed lands.

Under such conditions, irrigation is one of the most effective tools for reducing the negative impacts of climate changes on agricultural production, the implementation of which at the same time requires significant expenditures of water, energy, and other related resources. Therefore, the further restoration and development of irrigation require the implementation of natural based and ecologically sound solutions, which are an important condition for adapting agricultural production to existing global challenges and threats and for achieving the goals of sustainable development.

In addition, since the beginning of the full-scale war, the losses of cultivated areas in Ukraine caused by the temporary occupation and military actions amounted to more than 25 % of their total area, and the main part of these losses is the highly productive irrigated lands of the south and east of the country. After the terroristic attack of Russia at the Kakhovska HPP, which led to a further reduction of available arable land, the problem of the shortage of water resources for irrigation, [6] relevant both at the regional and planetary levels, reached the critical point, since the Kakhovska Reservoir itself was the source for irrigation of the lands of the south of Ukraine – the left bank of the Kherson region, partly in the Zaporizhzhia and Dnipropetrovsk regions. These are all consequences, the impact of which will be felt in the long term.

Analysis of recent studies and publications. Under the conditions of climate changes, aggravation of food, water, and energy crises, it is nature oriented and ecologically efficient solutions that can meet the needs of society and overcome social challenges in a natural sound way and in compliance with the principles of sustainable development based on more efficient use of natural resources, including water and energy [7].

In this regard, achieving and maintaining the country's food security in conditions of necessary resources shortage requires the implementation of nature oriented and ecologically effective solutions to increase the efficiency of irrigation, in particular by developing regime-technological and technical resource-saving measures and means that should be based on saving water and energy resources to ensure the process of crops irrigation.

In recent years, the trend for purposeful reduction of water use in irrigation has been spreading in the USA, where farmers deliberately reduce the yield of cultivated crops in order to save scarce and expensive water and energy resources [8–10]. Similar practices are used in China by implementing the so-called "deficit irrigation" [11–14]. However, this is done without the scientifically based recommendations for the implementation of such an approach.

Considering the above-mentioned, in modern conditions for achieving the goals of sustainable development, extremely relevant are the studies aimed at scientific substantiation of such decisions and of the levels of involved resources saving in the context of the effectiveness of irrigation implementation and agricultural production as a whole.

Thus, the **purpose of the conducted research** is to substantiate the feasibility and optimal decisions regarding the level of usage reduction of water and energy resources on the basis of resource optimization utilizing the results of evaluating the overall resources (technological), economic, ecological, and investment efficiency of irrigation at different levels of its sufficiency.

Research methods and materials. Modern changes in the irrigation systems functioning lead to the need for changes in methodological approaches to their creation and design, which should be based on a resource approach. New methodological approaches to the creation and functioning of irrigation systems, improvement of regime and technological aspects of irrigation, types, facilities, and parameters of irrigation systems adapted to these changes should be based not only on the evaluation of the effectiveness of adopted technical and technological solutions, but also take into account real operating conditions of the object, the level and trends in agricultural production, as well as, first of all, the amount of resources spent for its provision.

In the development of our earlier studies [15], with this approach, the substantiation of optimal solutions in the projects of construction, reconstruction, and operation of irrigation systems, considered as complex natural, technical, ecological, and economic systems, can be performed using the following complex optimization model

$$\begin{cases} U_0 = \underset{\{i\}}{extr}\, U_i, i = \overline{1, n_i}; \\ R_{0j} = \min\limits_{\{i\}} \left| R_{ji} - \widehat{R}_j \right|, j = \overline{1, n_j}; i = \overline{1, n_i} \end{cases} \qquad (1)$$

where U_o is the extreme value according to the accepted condition of the selected criterion of economic optimality U, which corresponds to the optimal technical and technological solution according to the set of possible options $I = \{i\}$, $i = \overline{1, n_i}$;

R_{ji} is a set of $\{j\}$, $j = \overline{1, n_j}$ criteria for the use of water and energy resources primarily involved in irrigation for appropriate options of technical and technological solution;

$\widehat{R}_j$ are the appropriate justified indicators of the criteria for the use of the involved resources.

Such a system of equations in a general implicit form makes it possible, on the basis of resource optimization, to theoretically substantiate the possibility of setting a problem, research, and consistently determine the optimal regime, technological and technical solutions for heterogeneous constituent elements and the system as a whole in their relationships both on empirical and empirical-functional level of determining the dependency between them.

In turn, the implementation of this model requires the application of a complex of forecasting-simulation, optimization, and economic-mathematical methods and models, which is embodied in the "Software package for the justification of design solutions during the creation and functioning of water management and reclamation facilities" [16]. It is a set of computer programs that make it possible to perform predictive simulations based on a number of indicators that characterize various aspects of irrigation in relation to the technological, ecological, economic, and investment components of the results of its implementation under multiple variable natural-agro-ameliorative conditions both at the level of a field and the specific crop and the level of the system and the projected term of its functioning. Their use is regulated by relevant industry standards of the State Water Agency of Ukraine [17–19, 27].

On the basis of the software package [16] for researching the impact of water and energy resource usage on changes in the productivity of cultivated crops, a computational experiment was planned and carried out to assess the overall efficiency of irrigation [20] with different modes of resource usage. For its implementation, we used the data obtained by us during the evaluation of the effectiveness of the vibration filter of the settling tank for irrigation water cleaning with various degrees of pollution in LLC "S-Rostok", Kherson region [21, 22].

The agricultural enterprise LLC "S-Rostok" is located in the Kakhovka district of Kherson region, Ukraine. Agricultural lands are represented by southern low-humus black soils. The main directions of production activity of the agricultural enterprise are the cultivation of grain, including high-quality food grain, technical crops, and vegetables. Irrigation of cultivated crops is carried out by sprinkling using sprinkler machines DMF "Fregat" modification DMU-Bnm 463-57-01.

The initial conditions for the computational experiment are as follows: **region** – Kherson**;** **natural and climatic zone** – Steppe; **calculation groups of years according to the conditions of heat and moisture sufficiency during the vegetation seasons** (very wet (p = 10 %); wet (p = 30 %); average (p = 50 %); dry (p = 70 %); very dry (p = 90 %)); **soils** – southern chernozems with low humus contents; **the set of crops of the project crop rotation with a share of their content** (perennial grasses (green mass) – 0,4; winter wheat (grain) – 0,2; vegetables (tomatoes) – 0.2; corn (grain) – 0,2).

The initial data used for the computational experiment regarding the irrigation rates and the cost of electricity for their supply with different sprinkler irrigation modes for the crops of the project crop rotation in terms of the level of resource consumption are presented in Table 1. For their characterization, the indicator of the ***level of irrigation sufficiency (φ, %)*** was introduced, which in the percentage equivalent characterizes the level of compliance of the studied irrigation regimes with its design regime, i.e. what is the percentage for watering **(φ_m, %)** and irrigation **(φ_M, %)** rates of their values with a certain irrigation regime relative to the design values.

The data on the changing the watering rates of the crops of the project crop rotation presented in Table 1 were obtained using the dependency between water losses along with the reduction of watering rate comparing to the projected one and different levels of irrigation water pollution during sprinkler irrigation in the process of the evaluation of the effectiveness of the vibration filter of the sump for cleaning irrigation water of various degrees of pollution [21, 22]. At the same

1. The values of watering rates and electricity consumption for crops irrigation from the project crop rotation with sprinkler irrigation regimes of different levels of sufficiency

Crops of the project crop rotation and indicators of the sprinkler irrigation regime		The level of irrigation sufficiency (φ_M, %)					
		100 % (designed)	73 %	70 %	67 %	62 %	52 %
perennial grasses (green mass)	watering rate *(m, m^3/ha)*	600	440	420	400	360	300
	electricity consumption *(ω_m, kWh/ha)*	200	147	140	133	120	100
vegetables (tomatoes)	watering rate *(m, m^3/ha)*	540	400	380	360	350	300
	electricity consumption *(ω_m, kWh/ha)*	180	133	127	120	117	100
winter cereals (grain)	watering rate *(m, m^3/ha)*	380	270	260	250	240	200
	electricity consumption *(ω_m, kWh/ha)*	127	90	87	83	80	67
corn (grain)	watering rate *(m, m^3/ha)*	420	300	290	280	260	220
	electricity consumption *(ω_m, kWh/ha)*	140	100	97	93	87	73

time, these data adequately reflect the situation when there are different levels of deviation of watering rates from their design values. They are consistent with the accepted concept of research on the impact of different consumption of water and energy resources on the changes in the productivity of cultivated crops under different irrigation regimes that correspond to different levels of its sufficiency.

Corresponding data on electricity consumption for supplying watering rates, as well as for all subsequent calculations, were obtained taking into account the unit cost of electricity for irrigation water pumping, which for the studied conditions in the Kherson region is 333.9 kWh/thousand m^3.

As the main variants of the study, the following set of modes of sprinkler irrigation, differing in the level of irrigation sufficiency, was considered:

– **control** – sprinkler irrigation according to the design mode, $\varphi_M = 100\,\%$;

– **option 1** – sprinkler irrigation mode, which is corresponds to $\varphi_M = 73\,\%$;

– **option 2** – sprinkler irrigation mode, which is corresponds to $\varphi_M = 70\,\%$;

– **option 3** – sprinkler irrigation mode, which is corresponds to $\varphi_M = 67\,\%$;

– **option 4** – sprinkler irrigation mode, which is corresponds to $\varphi_M = 62\,\%$;

– **option 5** – sprinkler irrigation mode, which is corresponds to $\varphi_M = 52\,\%$.

At the initial stage of predictive simulations, the data on changing watering rates (Table 1) were used for predictive assessment, according to which at the field level for each of the crops from projected crop rotation, calculation groups of years typical with respect to the conditions of heat and moisture sufficiency, and different irrigation regimes that correspond to different levels of irrigation sufficiency we evaluated the value of a set of different data on the water regime of the soil, technological indicators of irrigation, including irrigation rates and the corresponding values of the effective yield of the cultivated crops from projected crop rotation.

The obtained values of the specific indicators of irrigation rates and yields of crops from the projected crop rotation in relation to multiple variable conditions served as the basis for determining a number of relevant indicators that characterize the technological, economic, ecological, and investment efficiency of the studied options of sprinkler irrigation, presented in the form of weighted averages of their values at the level of the system and the project term of its functioning.

Research results and their discussion. An important issue in assessing the overall technological, ecological, economic, and investment efficiency of different irrigation regimes, which correspond to different levels of its sufficiency, is the selection and justification of criteria as a set of indicators that reflect various aspects of the effectiveness of their implementation. In this regard, a matrix of pairwise correlation coefficients was created, as an integral and important component of multi-criteria regression analysis, between disparate indicators characterizing various aspects of irrigation efficiency during the application of different irrigation regimes, which correspond to different levels of irrigation sufficiency [23, 24]. The input data of the performed multi-criteria regression analysis are the weighted average values of multiple heterogeneous specific indicators, which describe different aspects of irrigation efficiency during the application of different irrigation regimes, which correspond to different levels of irrigation sufficiency, obtained according to the results of predictive simulation.

The generalized results of such an analysis showed a fairly high level of connectivity between the following disparate indicators, which describe various aspects of irrigation efficiency (Table 2). φ_M – the irrigation sufficiency level (according to the irrigation rate), M – the irrigation rate, W – the electricity consumption, C – the cost of the gross product of the crop rotation, Ce – the current operating costs for irrigation, NI – the net income.

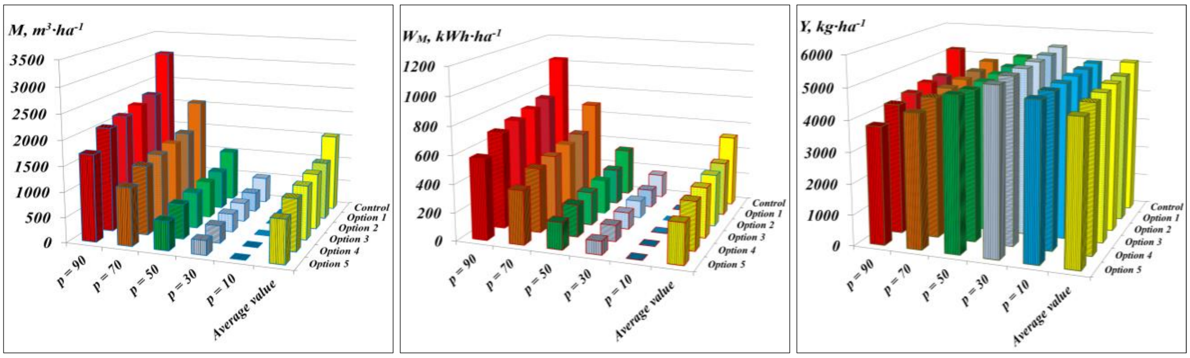
Based on the results of predictive simulations for the considered groups of years and crops from the projected crop rotation, changes in indicators of resource (technological) efficiency of irrigation were determined, namely, the values of irrigation rates and electricity consumption for sprinkler irrigation regimes with different levels of its sufficiency, and the resulting changes in the yield of cultivated crops as the main result of agricultural production, which directly determines the level of its economic efficiency.

A fragment of the obtained results, the case of the irrigation of winter wheat as the leading crop of the agricultural enterprise, which reflects the dynamics of changes in the values of the irrigation rate, electricity consumption, and yield of the cultivated crop according to the studied options at different levels of sprinkler irrigation sufficiency in relation to the calculation groups of years (very wet (p = 10 %) ; wet (p = 30 %); dry (p = 90 %); as well as their weighted average values are presented in Fig. 1.

The obtained results show that there is a clear dependency between the reduction of the irrigation rate, electricity consumption, and the decrease in the yield of cultivated crops. At the same time, the intensity of reducing the consumption of the relevant resources is significantly higher than the intensity of the decrease in the yield of cultivated crop. At the same time, under the conditions of the same level of irrigation sufficiency in relation to the calculation groups of years, and accordingly the level of reduction of water and energy resource consumption, the most significant reductions in the yield of winter wheat occur in drier years (under the conditions of medium (p = 50 %), dry (p = 70 %), and very dry (p = 90 %) years). The same conclusions are

2. Matrix of pairwise correlation coefficients between indicators characterizing the efficiency of irrigation implementation (R^2 = 0,8736)

Indicators	φ_M	M	W	C	C_e	NI
φ_M	1,0000	0,9153	0,8951	0,8758	–0,9061	0,8831
M	0,9153	1,0000	0,9523	0,8865	–0,9368	0,8803
W	0,8951	0,9523	1,0000	0,8853	–0,9145	0,8798
C	0,8758	0,8865	0,8853	1,0000	–0,8349	0,8721
C_e	–0,9061	–0,9368	–0,9145	–0,8349	1,0000	–0,8741
NI	0,8831	0,8803	0,8798	0,8721	–0,8741	1,0000



a *b* *c*

Fig. 1. Dynamics of changes in the values of the irrigation rate (*a*), electricity consumption (*b*) and the yield of the cultivated crop (*c*) according to the studied options at different levels of sprinkler irrigation sufficiency in accordance with the calculation groups of years in the case of the irrigation of winter wheat

typical for the rest of the cultivated crops.

Generalized among the set of crops from the projected crop rotation, the weighted average values of the indicators of the resource (technological) efficiency of sprinkler irrigation according to the studied options at different levels of its sufficiency for medium (p = 50 %), dry (p = 70 %), and very dry (p = 90 %) years, as those which are characterized by higher levels of expenditure of water and energy resources for irrigation from the entire set of calculation groups of years, are presented in Table 3.

A comparative assessment of the resource (technological) efficiency of sprinkler irrigation of the project crop rotation according to the studied options was carried out in relation to the weighted average values of the irrigation rate, electricity consumption, and productivity of the crop rotation for medium (p = 50 %), dry (p = 70 %), and very dry (p = 90 %) years, the results of which are presented on Fig. 2. At the same time, crop rotation productivity is calculated as a weighted average indicator based on the actual values of the yield of cultivated crops, presented in the form of degrees in relation to the potential climate-agrotechnically justified yield of these crops, the value of which is taken as 100 degrees.

The presented results showed that the studied options with different levels of irrigation sufficiency are generally technologically effective, when the intensity of crop rotation productivity reduction is more than twice as low as the intensity of water and electricity consumption reduction. At the same time, the intensity of the decrease in the productivity of the projected crop rotation has a clear dependency on the year of the calculated sufficiency – with an increase in the aridity of the year, it increases from 4.9–8.1 % for the conditions of an average year, and up to 22.9–41 % for the conditions of a very dry year, when the sensitivity of the impact increases with the reduction of irrigation rate values.

3. Generalized weighted average indicators of water and energy resources consumption during sprinkler irrigation according to the studied options for the conditions of medium (p = 50 %), dry (p = 70 %), and very dry (p = 90 %) years

Indicators of resource (technological) efficiency of sprinkler irrigation by calculation groups of years		**Studied option**					
		control	**option 1**	**option 2**	**option 3**	**option 4**	**option 5**
Consumption of irrigation water, m^3/ha	p = 50 %	1722	1263	1208	1154	1076	907
	p = 70 %	4012	2944	2815	2686	2491	2095
	p = 90 %	6698	4913	4698	4482	4155	3495
Consumption of electricity for irrigation water supply, kWh/ha	p = 50 %	575	422	403	385	359	303
	p = 70 %	1340	983	940	897	832	700
	p = 90 %	2237	1641	1569	1497	1388	1167

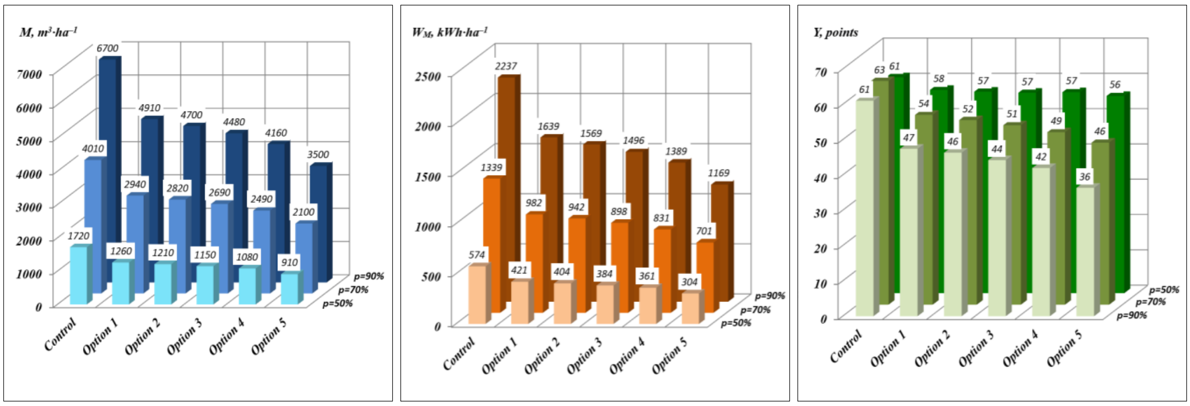


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Fig. 2. Comparative assessment of the resource (technological) efficiency of sprinkler irrigation of the projected crop rotation according to the studied options regarding the weighted average values of the irrigation rate (a), electricity consumption (b) and productivity (c) for medium (p = 50 %), dry (p = 70 %), and very dry (r = 90 %) years

The final decision regarding the expediency of reducing the consumption of water and energy resources can be made only on the basis of evaluating the economic and investment efficiency of irrigation according to the studied options.

According to [25, 26], the following indicators reflecting the economic component of irrigation efficiency were used to evaluate the economic efficiency of sprinkler irrigation of the projected crop rotation: *total current costs, UAH/ha; cost of gross production, UAH/ha; net income, UAH/ha; indicator of reduced costs taking into account weather and climate risk.*

Generalized among the set of crops from the projected crop rotation and calculation groups of years according to the conditions of heat and moisture supply during the growing season, the weighted average values of the main indicators of the economic efficiency of sprinkler irrigation of the projected crop rotation according to the studied options at different levels of irrigation sufficiency are presented in Table 4.

The sources of prices, which were used to calculate the main economic indicators presented in Table 4, are price tags, price lists, exchange prices, etc, as for 2019.

A comparative assessment of the change in average weighted values of resource (technological) and economic efficiency indicators of sprinkler irrigation according to the studied options relative to the control option is presented in percentages in Table 5.

The presented results (Table 4 and Table 5) showed that the studied options with different levels of irrigation sufficiency are generally economically profitable when the intensity of the decrease in the cost of gross production varies from 10.80 to 18.06 %, which is more than twice as low for the intensity of reducing water and electricity consumption from 27 to 48 %, with the achievement of net income from 11.4 to 5.7 thousand UAH/ha, respectively.

At the same time, the ecological component of the overall effectiveness of irrigation implementation consists in the decrease in the use of water and energy resources during the implementation of irrigation that a priori reflects the reduction of its negative impact on the environment. Therefore, these indicators can be used as possible criteria for evaluating the resource-ecological component of irrigation efficiency, which is a particular feature of the considered approach and meets the modern needs of changing approaches to the irrigation application under the conditions of climate changes, food, water, and energy crises, the transition of irrigated agriculture to nature oriented and resource-efficient solutions for achieving the sustainable development goals.

According to [27], the following indicators were used to evaluate the investment efficiency of sprinkler irrigation of the projected crop rotation: *investment profitability index, discounted net income, and discounted payback period.* The results of evaluating the investment effectiveness of sprinkler irrigation according to the studied options are presented in Table 6.

As shown by the results of the research of the impact of various studied options of reducing

4. Generalized weighted average values of indicators of economic efficiency of sprinkler irrigation according to the studied options

Indicators of economic efficiency	**Studied option**					
	control	**option 1**	**option 2**	**option 3**	**option 4**	**option 5**
Total current costs, UAH/ha	59632	56396	56438	56630	57453	56503
Cost of gross production, UAH/ha	76016	67808	67086	65901	65133	62285
Net income, UAH/ha	16384	11412	10648	9272	7679	5782
Indicator of reduced costs taking into account weather and climate risk	1,5	1,75	1,78	1,84	1,88	2,0

5. Comparative evaluation of the change in the weighted average values of the resource (technological) and economic efficiency of sprinkler irrigation according to the studied options

***Change in the values of resource (technological) and economic efficiency indicators**	**Studied option**				
	option 1	**option 2**	**option 3**	**option 4**	**option 5**
Reduction of water and electricity consumption, %	27	30	33	38	48
Decrease in the cost of gross production, %	10,80	11,75	13,31	14,32	18,06
Increase in the indicator of reduced costs taking into account weather and climate risk, %	16,67	18,67	22,67	25,33	33,33

Remark: 1. * – the data are indicated relative to the control version of the study; 2. Reduction of water and electricity consumption according to research options are identical, %

6. Indicators of investment efficiency of sprinkler irrigation according to the studied options

Indicators of investment efficiency	Studied option					
	control	option 1	option 2	option 3	option 4	option 5
Investment profitability index	2.24	1.68	1.60	1.44	1.26	1.05
Discounted net income, UAH/ha	89085	49007	42849	31755	18920	3625
Discounted payback period, years	5	7	8	9	10	14

the use of irrigation water on the indicator of the discounted payback period, several options may be acceptable according to this criterion, for which this indicator does not exceed the normative value of 10 years. Under such conditions, with the possible further implementation of the obtained results and the choice of the optimal option for implementation, it is necessary to take into account in each individual case, first of all, the limitations of availability and suitability of water resources for irrigation, the interests of investors and land users, availability of financial resources and opportunities, the scale of activities, the strategic importance of the object for economy, ecological acceptability and other conditions and criteria important for a specific object.

Conclusions. Thus, modern conditions and requirements for irrigation application, taking into account climate changes, the aggravation of food, water, and energy crises necessitate the transition to nature oriented and ecologically efficient solutions and changes in approaches for justification of optimal design solutions for the development and functioning of irrigation systems based on resource optimization. Such solutions meet the current needs for adaptation of various branches of economy, including irrigated agriculture, to existing challenges and threats along with the harmonization of their results with the concept of sustainable development of society, the main goal of which is systematically managed development with the establishment of a balance between meeting the modern needs of humanity and protecting the interests of future generations.

Therefore, reducing the consumption of water and energy resources during sprinkler irrigation is a fully justified decision from both a scientific and a practical point of view on the way to adapt irrigated agriculture to the modern conditions and requirements. Presented results showed that the intensity of the decrease in the productivity of cultivated crops, which is due to the decrease in the consumption of water and energy resources during the irrigation application, is significantly lower than the intensity of the decrease in the consumption of the resources themselves. This can be a scientific basis for the implementation of this approach in irrigation practice under existing changing conditions. That is why, the obtained results can be successfully used in the future for the justification of the nature oriented and ecologically effective solutions in irrigation in terms of implementation sustainable development concept in agricultural production under the conditions of global challenges and threats related to climate changes, water, food, and energy crises.

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СКОРОЧЕННЯ ЗАТРАТ ВОДНИХ Й ЕНЕРГЕТИЧНИХ РЕСУРСІВ ПРИ ЗРОШЕННІ НА ЗАСАДАХ РЕСУРСНОЇ ОПТИМІЗАЦІЇ

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Анотація. *Розглянуто необхідність подальшого розвитку зрошення на основі природоорієнтованих та екологоефективних рішень, насамперед щодо економії водних й енергетичних ресурсів для адаптації аграрного виробництва на зрошенні до наявних глобальних викликів і загроз та досягнення цілей сталого розвитку. Показано, що існує об'єктивна необхідність зміни методологічних підходів* *до оцінювання загальної ефективності й обґрунтування оптимальних рішень у проєктах будівництва, реконструкції та експлуатації зрошувальних систем за принципами ресурсної оптимізації. На основі введеного нами показника рівня забезпеченості зрошення, який відображає зниження досліджуваних поливних та зрошувальних норм щодо їх проєктних значень, виконано дослідження впливу зменшення використання водно-енергетичного ресурсу при різних режимах зрошення дощуванням на відповідне зниження рівня продуктивності вирощуваних сільськогосподарських культур. При цьому експериментально визначено, що інтенсивність (темпи) зниження продуктивності вирощуваних культур, яка зумовлена зниженням затрат водних й енергетичних ресурсів при реалізації зрошення, є суттєво нижчою за інтенсивність (темпи) зниження затрат самих ресурсів. Досліджувані варіанти скорочення затрат водних й енергетичних ресурсів в цілому виявились економічно рентабельними, коли при зниженні затрат води й електроенергії на 27–48 % має місце більш ніж удвічі нижче зниження вартості валової продукції на 10,80–18,06 % з досягненням чистого прибутку від 11,4 до 5,7 тис. грн. Вплив різних варіантів скорочення затрат води й електроенергії на дисконтований термін окупності інвестицій свідчить, що прийнятними можуть виявитись декілька варіантів, для яких термін окупності інвестицій не перевищує 10 років, а вибір оптимального рішення потребує врахування умов конкретного об'єкта, обмеженість водних ресурсів та інтересу інвесторів й землекористувачів. При цьому екологічна складова загальної ефективності реалізації зрошення полягає у тому, що зниження використання водно-енергетичного ресурсу апріорі відображає зниження негативного впливу зрошення на довкілля. Таким чином, скорочення затрат водних й енергетичних ресурсів є цілком виправданим рішенням на шляху адаптації аграрного виробництва на зрошенні до сучасних умов та вимог, а представлені результати можуть бути науковим підґрунтям впровадження даного підходу при реалізації зрошення на практиці.*

Ключові слова: *скорочення затрат, водні ресурси, енергетичні ресурси, зрошення, ресурсна оптимізація*