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Ecological problems of irrigated soils in the south of Ukraine

***Liudmyla Hranovska*[1],**
DSc (Economics), Professor, Head of the Department of irrigated agriculture,
[1]Institute of Irrigated Agriculture, NAAS Ukraine, Kherson, Naddnipryanske, 73483, Ukraine,
e-mail: G_Ludmila15@ukr.net, https://orcid.ogr000-0001-7021-3093;
***Oleksy Morozov*[1],**
DSc (Agriculture), Professor, Chief Researcher of the Department of irrigated agriculture,
e-mail: morozov-2008@ukr.net, https://orcid.org/0000-0002-5617-0813;
***Pavlo Pisarenko*[1],**
DSc (Agriculture), Professor, Chief Researcher of the Department of irrigated agriculture
e-mail: pavel_pisarenko74@ukr.net, https://orcid.org/0000-0002-2104-2301;
***Sergiy Vozhegov*[2],**
DSc (Agriculture), Chief Researcher,
[2]Rice Institute NAAS, Ukraine, Kherson region, vil. Antonovka, 75705, Ukraine,
e-mail: instofrice@gmail.com, http://orcid.org/0000-0003-0877-2593

ABSTRACT

Problem formulation. Ecological quality of soils and agricultural products depends on the level of irrigation water mineralization. The quality of mineralized irrigation water has a negative impact on soils, agricultural products and ecosystems. This is especially negative in the conditions of Southern Ukraine within the Black Sea territories where the formation of irrigation waters in the Ingulets river basin depends on the influence of the Kryvyi Rih iron ore basin located in the river basin.

The aim of the article is to assess the impact of mineralized irrigation waters on soils and natural ecosystems.

Materials and methods. Field sampling of water and dark chestnut saline soils and southern chernozem soils to determine the impact of mineralized water quality on soils and ecosystems, statistical analysis of the obtained data.

Results. Discharges of highly mineralized mine waters into the river basin lead to a change in the flow velocity in the river from 4 m^3/s to 20 m^3/s, which negatively affects the flora and fauna living conditions. Depending on the chemical composition of the discharges, the mineralization of irrigation water varies from 1.393 g/dm^3 to 1.7608 g/dm^3, and sometimes reaches 4.349 g/dm^3. In terms of chemical composition, irrigation water is formed as a hydrocarbonate-sulfate-chloride with almost the same content of sulfates and chlorides, calcium-magnesium-sodium with a significant advantage of sodium. The dynamics of irrigation water quality indicators during 2013-2021 testifies to an increase of the most dangerous indicators for soils: hydrogen index of soil solution (pH) from 7.7 to 8.4, chlorine ion content (Cl^-) – from 9.52 to 10.77 meq/dm^3 and sodium (Na^+) from 9.52 to 13.33 meq/dm^3. By means of correlation and regression analyzes, the regularities of water hydrochemical composition formation were revealed and a strong functional connection between mineralization and chlorine ions ($r = 0.99$) and sulfate ions ($r = 0.99$), between mineralization and hydrocarbonate ions was established ($r = 0.47$). As the mineralization of water increases, the content of chlorine ions and sulfate ions increases proportionally, and hydrocarbonate ions play a secondary role in the formation of the hydrochemical composition. To prevent the chlorine ions excess of more than 350 meq/dm^3 and sulfate ions excess – 500 meq/dm^3, irrigation water mineralization should not exceed 1500 mg/dm^3, and to prevent the chlorine ions excess of more than 350 meq/dm^3, water flow from the canal should be at least 9.0 m^3/s.

Scientific novelty. New mathematical models of the irrigation water mineralization, its anionic composition, its chloride content dependence on water consumption from the Ingulets river and the interdependence between mineralization and cationic composition of water are offered.

Practical significance. The obtained results are of practical importance for the implementation of agro-ameliorative measures for soil and ecosystem conservation.

Keywords: *mineralized waters, irrigation water, salinization, agro-ameliorative measures, soil reclamation, ecosystem.*

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Problem formulation. Natural ecosystems on arid lands are sensitive to irrational use of nature, including the use of land reclamation, and can easily result in imbalance and degradation: soil degradation and desertification, depletion of water resources and loss of biodiversity. The most complex forms of soil degradation are the processes of natural salinization and alkalinization which are associated with the use of highly mineralized water for agriculture. According to the Concept of Sustainable Development, agriculture aims at ensuring food security of the country under the condition of rationally using natural resources potential, the protection and restoration of natural resources, including soils [1,2].

The processes of soil degradation and desertification caused by natural and secondary salinization and alkalinization and the outcome of their irrational use are a characteristic phenomenon for many countries around the world, as well as for Ukraine. The reasons for this process in Ukraine are not only the

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natural land aridity which is accompanied by insufficient rainfall, negative water balance and related conditions of soil formation processes, but also natural salinization and alkalinization of soils, especially those located within the Black Sea territories.

The Black Sea territories adjacent to the Black and Azov Seas are characterized not only by the consequences of the Black Sea complex geological history, but also by the consequences of the sea basin effect on soil formation processes. Sources of salt accumulation in the soils and groundwater of these areas are sea salts that are accumulated in estuarine and marine sediments, and also come from sea water during periodic flooding. In addition, salts come underground. Another source of salt accumulation in coastal areas is impulverization, that is, the transfer of salts by wind, which is one of the ways of salt exchange. About 180-320 kg of salts per 1 ha can be transferred to the soil surface by wind [3]. The process of solonetzic soils formation and evolution in the Black Sea region, as well as in the Dnieper estuary can be considered as the soil development from hydromorphic saline to solonetzes and dark chestnut ones depending on terrain rising and groundwater levels lowering.

Both surface and ground waters are used for irrigation in Ukraine but they have different effects on soil, crop products and ecosystems in general. Much of the irrigation sources of both surface and groundwater are mineralized waters which have a negative impact on the Black Sea ecosystems and agricultural products.

The aim of the research is ecological assessment of the mineralized irrigation waters effect on the soils and natural resources of the South of Ukraine. The research was conducted on agricultural lands of the Black Sea territories using the mineralized irrigation water.

Discussion. A number of scientific publications by domestic and foreign scientists are devoted to the study of the peculiarities of the mineralized waters use and their impact on soils and natural ecosystems. The analysis of these research results shows that the considerations of some scientific provisions concerning the rational use of water resources [for example 4,5,6,7] and assessment of the quality of the mineralized irrigation water supplied by the Ingulets Canal as well as the substantiation of its hydrochemical composition aspects were performed. Scientists focus the attention of land users in arid regions on climate change and the need for environmentally friendly nature management [3,4]. Many years of research by domestic scientists have shown that water used for irrigation in southern Ukraine has high mineralization and unacceptable ratio of monovalent and divalent cations, as well as high chlorine content, and adversely affects the quality of agricultural products and soils [8,9]. Research by the Institute of Irrigated Agriculture, NAAS, found that the use of highly mineralized irrigation water for irrigation of southern chernozems promotes degradation processes in soils, their secondary salinization and alkalinization processes, which negatively affects the state of ecosystems and quality of agricultural products [10, 11].

Assessing the quality of irrigation water in order to determine its impact on soil fertility is one of the pressing problems of modern irrigated agriculture, as noted by domestic and foreign scientists [12, 13, 14, 15, 16]. The quality of irrigation water was studied in the 60-70s of the last century in many countries around the world, and the first scientific articles on this issue were published in 1976 in the United States, according to foreign scientists [17]. However, so far, the main methodological and conceptual approaches to combating poor quality water, which causes salinization and alkalinization, require revision, research and improvement. At the same time, foreign scientists identify four main criteria for assessing water quality for irrigation, including water salinity (WS), sodium hazard (sodium adsorption coefficient - SAC), residual sodium carbonate (RSC) and ionic toxicity, as well as toxicity of boron ions and chlorides to plants. It should be borne in mind that under the influence of climate change towards warming "soil salinity increases over time, and for sustainable management of saline soils it is important to diagnose salinity in time before taking appropriate measures to intervene in soils" [18, 19, 20, 21].

The accumulation of salts in soils is also associated with irrigation of agricultural land and can be caused by two main reasons: high level of saline groundwater and insufficiently scientifically substantiated irrigation regime, such as excess of irrigation water without artificial drainage, which leads to increased level of soil salinity and reduced crop yields [15, 22, 23, 24]. Salinity has a negative effect on the biological and microbiological functions of soil, its buffering capacity and pollutants filtration [25,26]. Soil is unable to participate in hydrological and nitrogen cycles and maintain biodiversity. In addition, disruption of soil biological activity leads to significant risks and environmental stress for soils and ecosystems, it reduces crop yields (by 18 - 43%) and threatens the country's food security. However, irrigation in the areas with insufficient natural moisture ensures agricultural efficiency and food security. Experts in the field of irrigated agriculture in Central Asia note that irrigation has negative consequences, as significant amounts of salt are transferred to the soil, where they are accumulated in the lowest places or return to the river, thus increasing the mineralization of the river water used for irrigation [14]. Mineralized water has a negative impact on ecosystems, humans and agriculture, as under prolonged irrigation with mineralized waters the salt composition of dark chestnut soils changes [11, 27, 28, 29, 30].

The analysis shows that irrigation with mineralized waters has a negative effect on the chemical composition of the soil solution by increasing the pH (hydrogen index of the soil), soil solution electrical conductivity and SAC which determines the ratio of cations in water and activity of sodium ions and its ability to enter the soil. In addition, as researchers note, if mineralized water is used for irrigation, the concentration of ions CO_3^{2}, Na^+, HCO_3^-, Cl^-, which form toxic salts, also increases [36].

Materials and methods. The research uses generally accepted methods and methodological approaches to research used in domestic and international practice, namely: system approach and system analysis, monographic analysis and synthesis, abstract-logical, historical, methods of field research of soils (dark chestnut solonetzic and southern chernozems) and assessment of irrigation water quality using rapid analysis, as well as statistical and mathematical methods using variance, correlation, regression analysis to achieve the research goal.

The research was conducted in the areas of the Black Sea lowland, which is adjacent to the Black and Azov Seas and where the mineralized waters of the Ingulets irrigation system are used for irrigation.

Soil samples were taken during 2018-2021 in both southern chernozems and dark chestnut solonetzic soils in the area of the Ingulets irrigation system affected by mineralized waters (Fig. 1). Sampling was carried out according to Ukrainian State Standards (USS) ISO 5667: 2009 [31], and analytical studies were performed in a certified laboratory of analytical studies of the Institute of Irrigated Agriculture, NAAS; pH was determined by electrometric method; chlorides and total alkalinity were determined by titration [32, 33]. Assessment of the condition of irrigated southern chernozems and dark chestnut solonetzic soils was carried out according to USS 3866-9 "Soils. Classification of soils according to the degree of secondary salinity" [35].

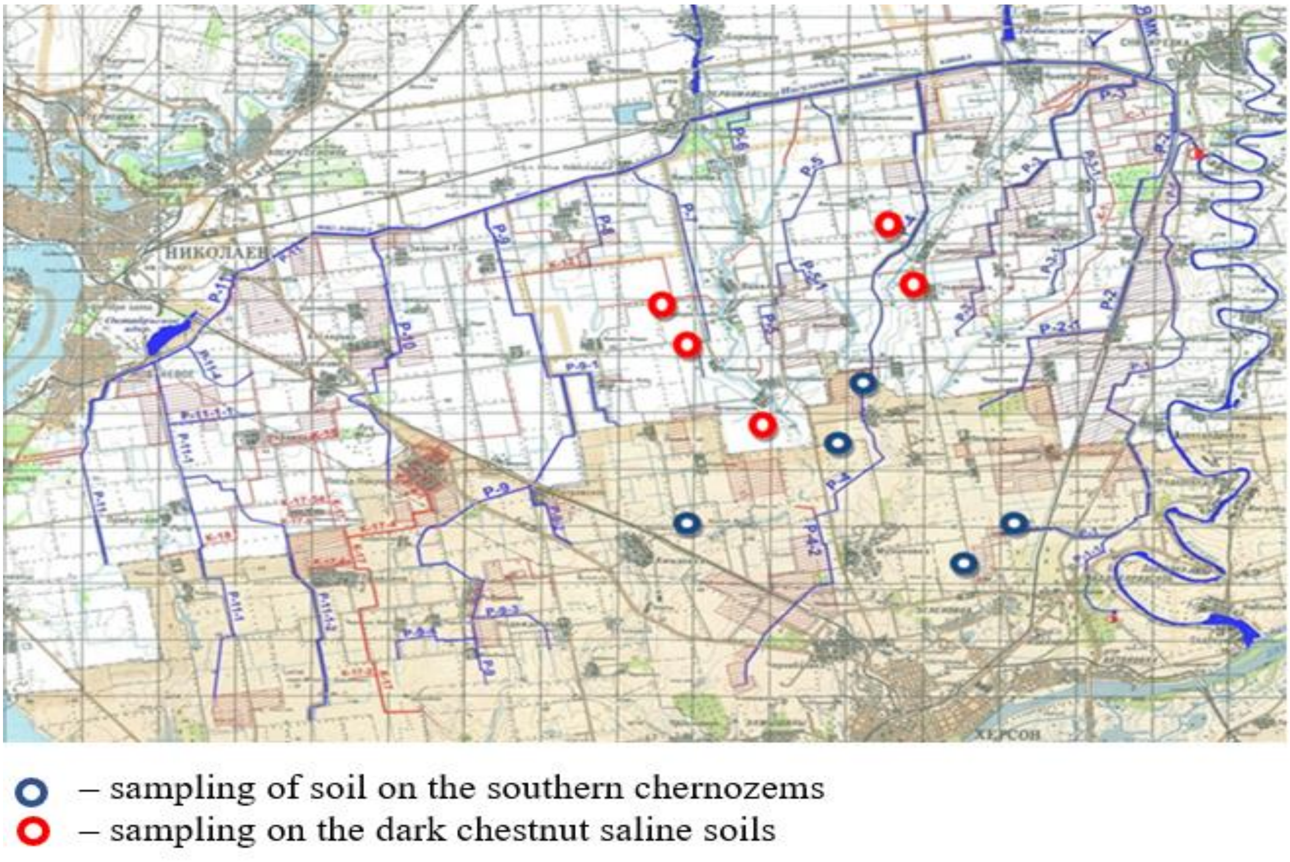


Fig. 1. Soil sampling points

Water samples were taken at certain points in the Ingulets River and in the Ingulets Irrigation Canal according to the relevant scheme (Fig. 2). Samples were taken during 2013-2021, which made it possible to form a considerable database for analysis.

Assessment of irrigation water quality was carried out according to USS 2730: 2015 "Quality of natural water for irrigation. Agronomic criteria", which establishes agronomic criteria for determining the quality of natural water used for irrigation, as well as the degree of its impact on soils [34].

Results. The analysis shows that irrigation with mineralized waters has a negative effect on the chemical composition of the soil solution due to increased pH (hydrogen index of the soil), electrical conductivity of the soil solution and SAC, which de-

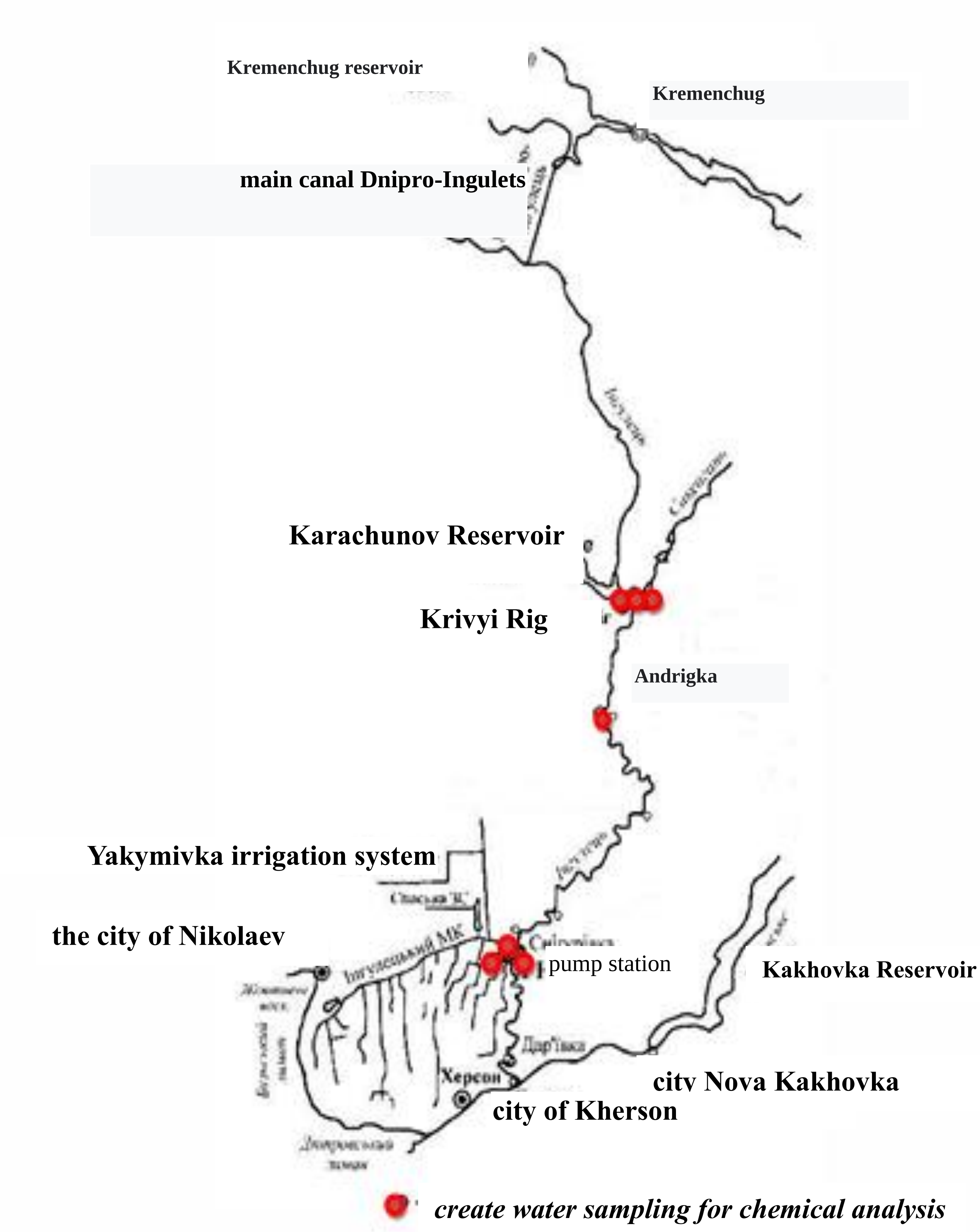


Fig. 2. Water sampling points in the main canal and in the Inguletsriver

termines the ratio of cations in water and sodium ion activity and its ability to enter the soil solution. In addition, as researchers note, if mineralized water is used for irrigation, the concentration of ions $CO3^{2}$, Na^{+}, $HCO3^{-}$, Cl^{-}, which form toxic salts, also increases in the soil solution [36].

Using mineralized irrigation waters on the soils of southern Ukraine which naturally had a significant level of salinity, makes the situation especially difficult. And the formation of irrigation water in the Ingulets river basin has its peculiarities, which are due to the fact that the quality of Ingulets water is significantly affected by the Kryvyi Rih iron ore basin located in the Ingulets basin. Kryvyi Rih iron ore basin is the largest in Ukraine and in the world and is located in the Dnipropetrovsk region. Extraction and processing of iron ore requires significant amounts of water, so the mining enterprises of Kryvbas accumulate a significant amount of return water, which causes its overflow, thus threatening an emergency situation in Ukraine.

Longstanding discharge of mine water from the Kryvyi Rih iron ore basin into the Ingulets River caused a significant deterioration of the ecological situation in the river catchment area. At the same time, the river changes its hydrological regime four times in just one year, which necessitates the adaptation of bioresources to such changes. Deterioration of river water quality due to discharges of highly mineralized mine waters and the negative impact of these waters on the ecosystem leads to the change in the river flow velocity from 4 m/s to 20 m/s, which negatively affects the living conditions of flora and fauna. The ecological parameters of the river ecosystem and its chemical and sanitary-hygienic indicators are also deteriorating due to uncontrolled discharges by other enterprises and individuals. No measures are taken to improve the ecological conditions for flora and fauna development, for restoring the bioresources of the entire ecosystem which is in critical condition. In addition, irrigation with highly mineralized water continues. The results of irrigation water quality assessment for the period of 2013-2021 are given in Table 1. Mineralization during this period varied from 1,393 g/dm³ to 1,7608 g/dm³, and sometimes reached 2,349 g/dm³.

Graphic representation of the irrigation water quality indicators dynamics during 2013-2021 is presented in Figure 3.

Irrigation water quality assessment was carried out according to the current state standard USS 2730: 2015 "Quality of natural water for irrigation. Agronomic criteria" (Table 2).

The analysis shows a deterioration in the irriga-

Table 1

Irrigation water quality, meq/dm³

Year, average	pH	CO_3^{2}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	Mineralization, g/dm³
2013	8,0	0, 44	3,58	9,52	8,64	4,92	7,32	9,52	1,391
2014	8,4	0,64	3,23	9,97	9,53	3,80	7,33	12,03	1,462
2015	7,9	no	3,64	10,72	10,20	4,70	7,50	12,36	1,560
2016	8,0	no	3,64	9,30	10,50	4,10	7,90	11,44	1,496
2017	7,7	0.32	3,58	9,50	9.44	4,32	7,40	10,87	1,420
2018	7,9	0.32	3.57	11,73	11,60	4,87	8,30	13,81	1,708
2019	8,1	0,32	3,49	11,19	11,33	4,70	8,00	13,53	1.653
2020	8.0	0.40	3,25	10,67	8,97	4,49	6,57	13,10	1,484
2021	8,0	0,48	3,50	10,77	10,07	4,50	8,10	13,33	1,624

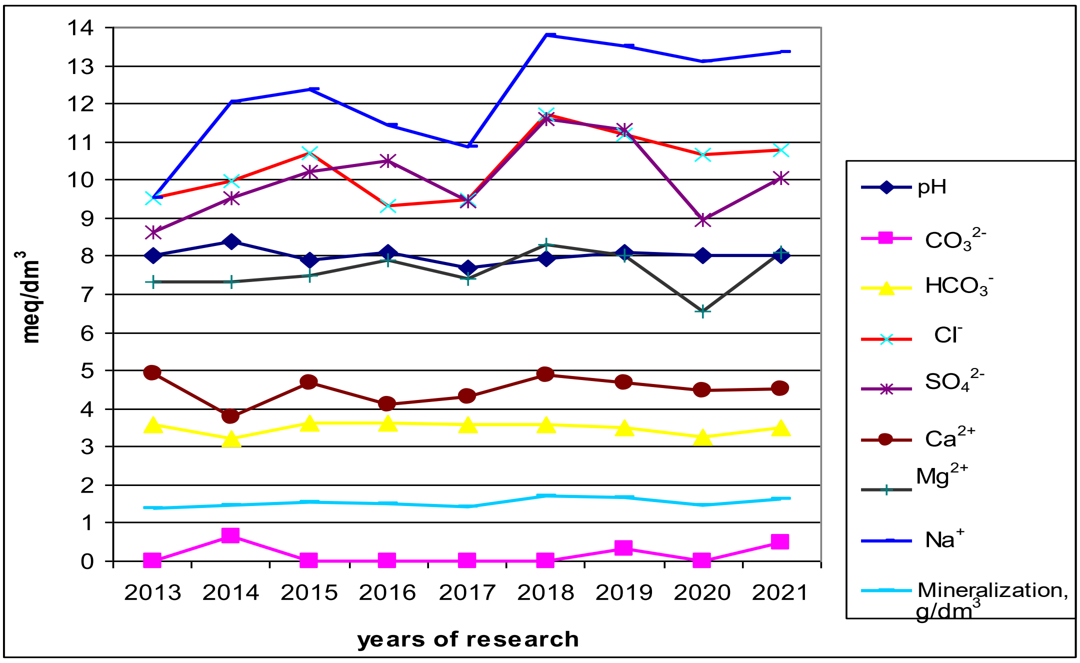


Fig. 3. Dynamics of Ingulets irrigation water quality indicators for the period 2013-2021

Table 2

Mineralized irrigation water quality assessment (2013-2021)

Evaluation indicators	Calculation methods	Permissible criteria	Values	Conclusion
pH (hydrogen index) of irrigation water		6.0 – 7.5	7.3-7.5	suitable
Mineralization, g / dmi		Up to 0.45 g/dmi – class 1, suitable for irrigation; 0.45-1.0 g/dmi - limited suitability; More than 1.0 g/dmi - unsuitable.	1.49 g/dm^3	Class 3 water is not suitable for irrigation
Assessment of irrigation water quality as to the risk of soil salinization	Evaluation is based on the amount of toxic salts in chlorine ion equivalents, taking into account the particle size distribution of the soil	Less than 18 meq/dmi	15.06 meq/dmi	Suitable
Assessment of irrigation water quality as to the risk of soil alkalinization	pH; CO_3 content, meq/dmi; Toxic alkalinity content of HCO_3-Ca, meq / dmi;	pH less than 7.5; CO_3 - absent; HCO_3-Ca less than 2.0;	pH less than 7.5; CO_3 - absent; HCO_3-Ca = 0.130 mEq/dm^3;	Suitable
Assessment of irrigation water quality as to the risk of soil alkalinization	The ratio of the alkaline cations and potassium, taking into account the magnesium content, to the sum of all cations, %	Less than 65 – class 1;	55.00%	Suitable
Assessment of irrigation water quality as to the danger of its toxic effects on plants	The evaluation is performed on the basis of hydrogen pH, alkalinity content from normal carbonates (CO_3) and anion content (Cl^-).	pH 6.5-7.5; CO_3 - absent; Cl^- - less than 3.0 meq/dm^3;	pH 7.5; CO_3 - absent; Cl10.88 = $^-$meq/dm^3;	Water is toxic to all plants in terms of SI content
Coefficient that determines the risk of alkalinization (according to I.P. Aidarov-O.I. Golovanov)	$\frac{Na^+ * 100\%}{Ca+Mg} = K$	K less than 25% Ukrainian State Standard 2730: 2015	K=104.5%	Unsuitable

tion water quality throughout the research period, especially the increase of the most dangerous indicators: aqueous soil solution (pH) and chlorine (Cl^-) and sodium (Na^+) content. Due to the constant inflows of the Dnieper water, the appropriate level of irrigation water mineralization in the irrigation canal (1.4–1.6 g/dm^3) is maintained which corresponds to quality class 2. In terms of chlorine ions, water remains toxic to all plants. In terms of sodium content, the Ingulets irrigation water causes active processes of soil secondary salinization and is of limited suitability for irrigation (Class 2 according to USS 2730: 2015 "Quality of natural water for irrigation. Agronomic criteria").

In order to identify the features and patterns of irrigation water hydrochemical composition formation, data correlation and regression analyses were performed (Table 2). Correlation-regression analysis showed a strong functional relationship between irrigation water mineralization and chlorine ions (r =

0.99) and sulfate ions (r = 0.99) content and weak connection between the irrigation water mineralization and bicarbonate ions (r = 0.47) content.

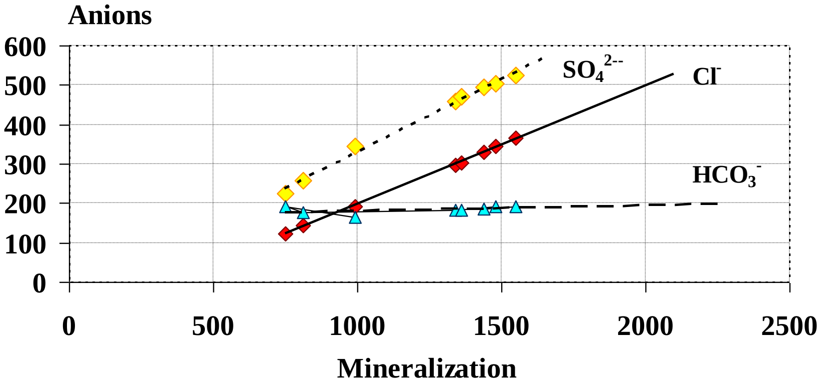
As the irrigation water mineralization increases, the content of chlorine ions and sulfate ions increases proportionally, hydrocarbonate ions play a secondary role in the formation of the irrigation water hydrochemical composition. Regression equations, correlation coefficients are shown in Figure 4.

To prevent the chlorine ions excess of more than 350 mEq/dm³ and sulfate ions excess of more than 500 mEq/dm³, the mineralization of irrigation water should not exceed 1500 mg/dm³.

In the conditions of the Regulations of riverbed washing and ecological rehabilitation of the Ingulets river, the peculiarities and regularities of the chloride content formation in the Ingulets river surface waters depending on water consumption are revealed (Fig. 5)

Data correlation and regression analyzes have been performed. A strong functional relationship between the chloride content in the surface waters of the Ingulets River and water consumption (correlation coefficient (r) 0.85, determination coefficient (R^2) 0.728) has been established.

As the flow of water from the canal increases, the content of chlorine ions decreases proportionally. To prevent the chlorine ions excess of more than 350 meq/dm³, water flow from the channel must be at least 9.0 m³/s.



Anions	Regression equation	Determination coefficient	Correlation coefficient
Cl^-	Y = 0.3x – 101.65	R^2 = 0.9992	r = 0.99
SO_4^{2-}	Y = 0.3706x – 40.292	R^2 = 0.9935	r = 0.99
HCO_3^-	Y = 0.0138x + 167.0	R^2 = 0.2171	r = 0.47

Fig. 4. Dependence of irrigation water mineralization and anionic composition

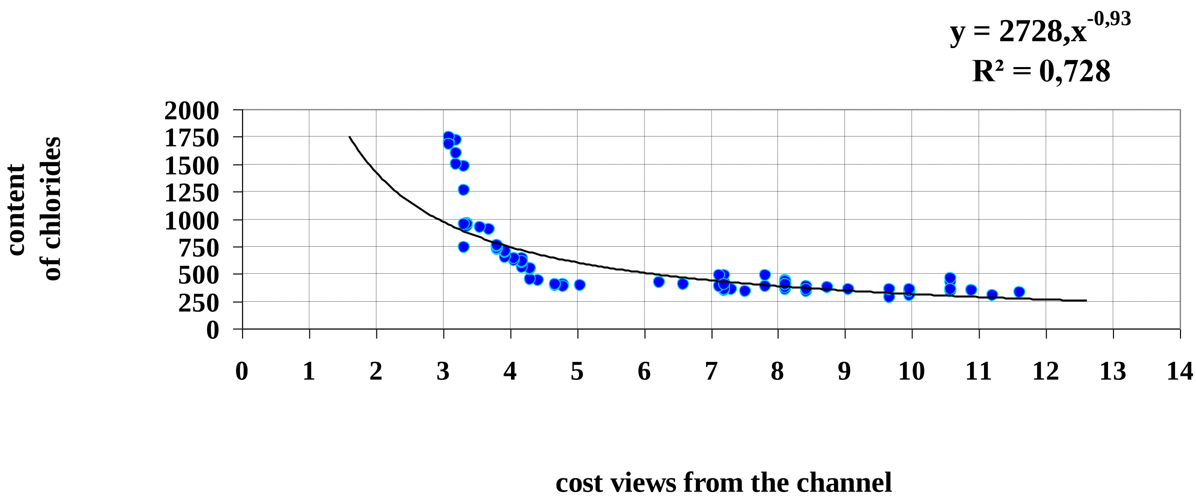


Fig. 5. Dependence of chloride content on water consumption of the Ingulets River

The average annual ratio of days when the water quality in terms of chloride content exceeds 350 mg/dm³ in 2018-2021 was 66.20%, in 2011-2017 - 17.37%; when it was more than 400 mg/dm³, 35.96 and 2.86% respectively; when it was more than 450 mg/dm³, 23.02 and 0.88% respectively; when it was more than 500 mg/dm³, 17.62 and 0.55%, respectively (Fig. 6).

As a result of research, the percentage of days when the chloride content in the Ingulets River water exceeded the value of 350 mg/dm³; 400 mg/dm³; 450 mg/dm³; 500 mg/dm³ (taking into account the start and end dates of riverbed flushing's and the timing of water reaching the sampling points in the Ingulets River) was determined.

That is, in 2018-2021 there was a significant deterioration in the Ingulets River water quality. To prevent the chlorine ions excess of more than 350 mEq/dm³ and sulfate ions excess of more than 500 mEq/dm³, the mineralization of irrigation water should not exceed 1500 mg/dm³.

As the irrigation water mineralization increases, the content of magnesium and calcium ions will increase proportionally, and sodium and potassium ions play a secondary role in the formation of the mineralized irrigation water hydrochemical composition. The regression equations and the calculated correlation coefficients are shown in Fig. 7.

In the conditions of the Regulations of river bed flushing and ecological rehabilitation of the Ingulets river, the peculiarities and regularities of chloride content formation in the Ingulets river surface waters depending on water consumption, which negatively affects the irrigation water quality, were revealed.

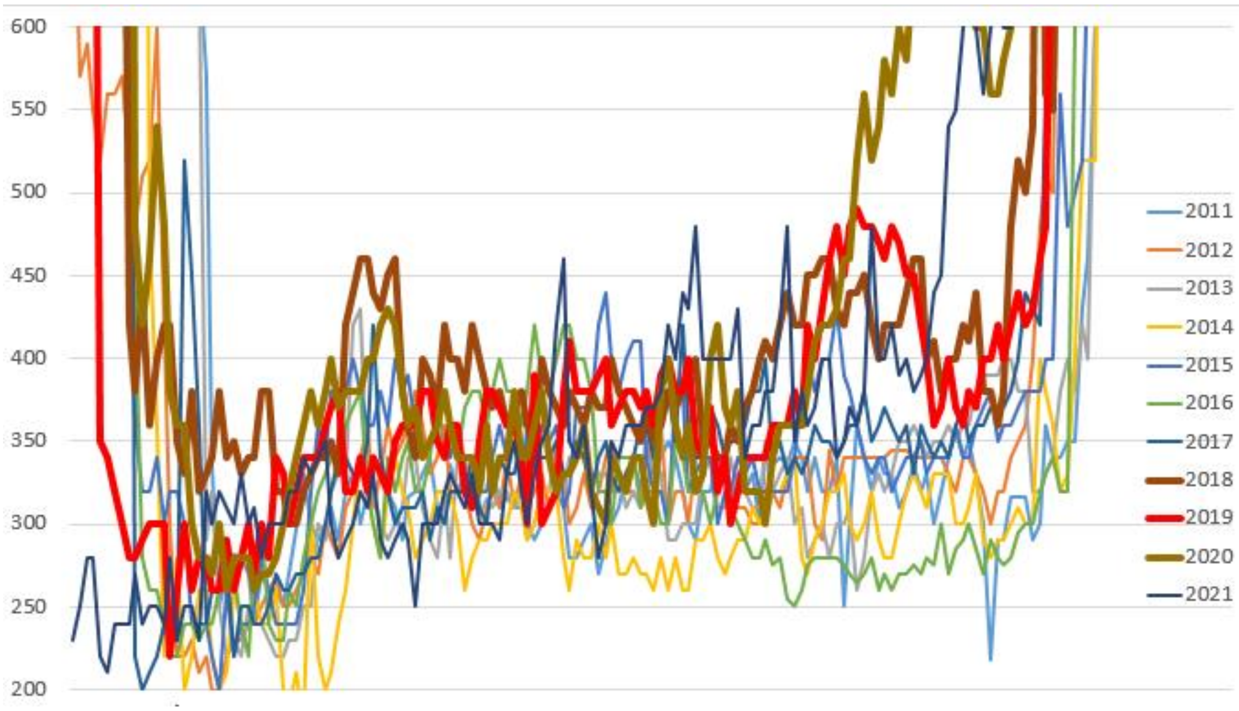
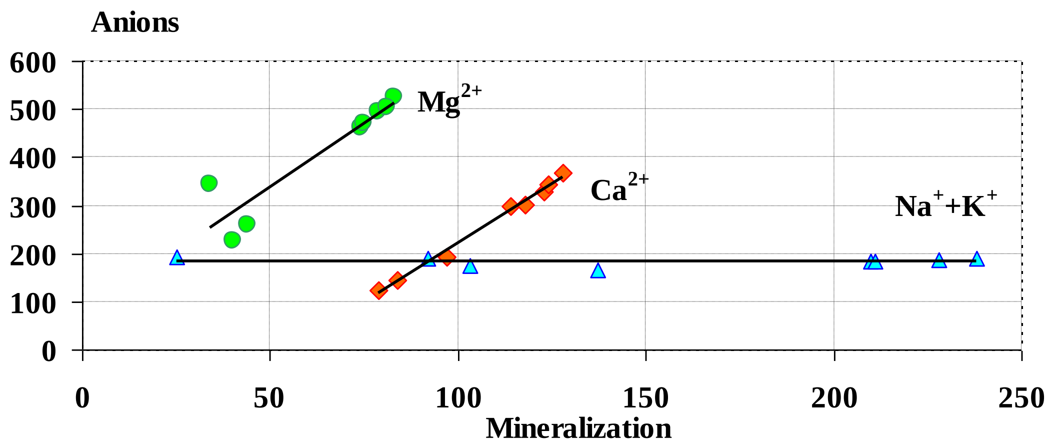


Fig. 6. Dynamics of chloride content in the Ingulets river water



Anions	Regression equation	Determination coefficient	Correlation coefficient
Mg^{2+-}	Y = 5.2704x + 74.012	R^2 = 0.8521	r = 0.92
Ca^{2+}	Y =4.9546x - 274.08	R^2 = 0.9933	r = 0.99
$Na^{+}+K^{+}$	Y = -0.0026x + 184.15	R^2 = 0.0004	r = 0.02

Fig. 7. Interdependence of irrigation water mineralization and its cationic composition

All of the above requires a scientifically sound attitude to using natural sources for crops irrigation, it requires constant monitoring of irrigation water quality indicators and a set of measures to improve its quality and prevent soil fertility deterioration.

The research was conducted to assess the impact of the mineralized Ingulets irrigation water quality on the fertility of southern chernozems and dark chestnut saline soils of the Ingulets irrigation area which for many years are irrigated with water of suitability class 2. The research results are shown in table 3. Soils represented by southern chernozem are characterized by an average humus content (2.85%), average content of nitrate nitrogen, mobile phosphorus and metabolic potassium; they are not saline and have a medium and high level of secondary salinization. The pH of the soil salt extract testifies to the progressing process of soil alkalization. Dark chestnut medium-saline soils are characterized by a medium content of nitrate nitrogen, mobile phosphorus and exchangeable potassium; the humus content (2.32%) and further on the profile is low (1.35%); the soils are not saline and have a high level of secondary salinization; high pH values of the soil salt extract testifies to the alkalinization process which is associated with the Ingulets irrigation water quality.

Table 3

The results of the agrochemical research of southern chernozem and dark chestnut solonetzic soils under long-term irrigation with mineralized irrigation water (2013-2021)

Indicators	Values for Ingulets irrigated area soils, mg/kg		Criteria of indicators, mg/kg	Conclusion as to requirements of USS 4362: 2004 Soil quality. Fertility rates
	southern chernozem	dark chestnut saline		
1.Content of nitrate nitrogen NO_3 in soil layers:	13.01.21	01.09.43	9-15	average content
2.Mobile phosphorus content P_2O_5	20.01.21	24.09.21	21-45	average content
3. Potassium exchange content K_2O	359	484	200-400	average content
4. Humus content	01.02.85	01.02.32	2.1-3.0	average content
5. pH of the soil salt extract	6.8-7.8	7.7-8.1	6.1-7.5 7.6-8.0	directed towards alkalinity, alkaline
6. The amount of salts in% by soil weight	0.068-0.156	0.068-0.107	≤ 0.2%	the soil is not saline
7.The degree of salinization is determined by the ratio of sodium to the amount of calcium and magnesium	0.11-3.44	0.9-1.8	the ratio must be less than one	The soil is alkainized

When mineralized irrigation water with high content of chlorides, sulfates and sodium salts is applied to agricultural lands, the process of salinization and alkalinization is actively progressing and toxic chlorine and sodium salts are accumulated in soils and river ecosystems. The wastewater of the Kryvyi Rih iron ore basin getting into the Ingulets River affects negatively the natural ecosystems. After the discharge of excess return water, measures are implemented to eliminate the consequences of the discharge by flushing the Ingulets riverbed. Such activity is potentially dangerous for the environment under certain conditions, because such periodic discharges of highly mineralized excess return water make it impossible to comply with current standards of surface water quality. But this action is justified because it is carried out solely to prevent more serious and large-scale man-made consequences which will be associated with the shutdown and flooding of existing mines, regional mineralized groundwater rising, pollution of upper aquifers and surface waters, with large-scale upheavals. Such an emergency may cause the ecological imbalance and threaten various important areas of economic activity and social life not only in the Kryvyi Rih iron ore basin but also far beyond.

During many years of irrigation water formation within the Ingulets irrigation area and the Black Sea coast of Ukraine, a very difficult ecological situation has developed which requires radical economic and cost-effective measures.

However, the provision of the Black Sea region with agricultural products requires the development of irrigation and the use of different quality irrigation waters. So it is necessary to implement appropriate measures to reduce the negative impact of mineralized waters on soils and ecosystems.

To prevent the processes of secondary salinization, it is necessary to carry out chemical reclamation by applying calcium-containing ameliorants to the soil: application of gypsum or phosphogypsum at the rate of 5-6 tons per hectare. Phosphogypsum is more effective than natural gypsum, as it dissolves better in soil solutions. Phosphogypsum is applied for 3 years: in the spring for cultivation (3 t/ha) or in autumn for the main tillage (at a dose of 6 t/ha). Phosphorus in it (up to 4%) is absorbed by plants.

In addition, calculations are additionally made as to the frequency of phosphogypsum application based on the ratio of sodium cations and the amount of calcium and magnesium in the aqueous extract.

Studies have shown that the quality of Ingulets irrigation water deteriorates over the years as to its most toxic indicators, which has a negative impact on soil fertility. To suspend the processes of secondary salinization it is necessary to implement agro-ameliorative measures, provide the Ingulets River regular flushing, chemical reclamation of secondary saline soils and irrigation water.

Conclusions. The ecological condition of soils irrigated with mineralized waters of the Ingulets irrigation system has significantly deteriorated during the period of 2013-2021. When mineralized irrigation water with high content of chlorides, sulfates and sodium salts is applied to agricultural lands, the process of salinization and alkalinization is actively progressing, while toxic chlorine and sodium salts are accumulated in soils. Increased mineralization of irrigation water and the deterioration of its environmental performance depends on the regulation of highly mineralized water discharges in the Kryvyi Rih iron ore basin into the Ingulets River. As the mineralization of water in the Ingulets River increases, the content of toxic anions and cations in the irrigation water of the Ingulets Canal increases as well. And it is just the implementation of the Ingulets riverbed flushing and its ecological rehabilitation using the Dnieper water and increasing the water flow from the canal that can help to reduce the content of toxic ions.

To improve the ecological condition of soils irrigated with mineralized waters and prevent secondary salinization processes, it is necessary to carry out chemical reclamation by adding calcium-containing ameliorants to the soil: gypsum or phosphogypsum at the rate of 5-6 tons per hectare. Phosphogypsum acts on the soil more effectively than natural gypsum, as it dissolves better in soil solutions. Phosphogypsum is applied for 3 years: 3 t/ha in spring or 6 t/ha in autumn. Phosphorus in it (up to 4%) is also actively absorbed by plants. In addition, calculations are made concerning the periodic application of phosphogypsum by determining the ratio of sodium cations and the amount of calcium and magnesium in the aqueous extract. If it exceeds 1, then there is a need to re-introduce phosphogypsum.

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Вплив мінералізованих поливних вод на ґрунти та екосистеми

Людмила Грановська[1]***,***
д. екон. н., професор, зав. відділу зрошуваного землеробства,
[1]Інститут зрошуваного землеробства НААН,
м. Херсон, сел. Наддніпрянське, 73483, Україна;
Олексій Морозов[1]***,***
д. с.-г. н., професор, гол. наук. співроб. відділу зрошуваного землеробства;
Павло Писаренко[1]***,***
д. с.-г. н., ст. наук. співроб., гол. наук. співроб. відділу зрошуваного землеробства;
Сергій Вожегов[2]***,***
д. с.-г. н., ст. наук. співроб., гол. наук. співроб., [2]Інститут рису НААН

Екологічна якість ґрунтів і сільськогосподарської продукції залежить від рівня мінералізації поливної води. Особливо негативно це проявляється в умовах Півдня України в межах Причорноморських територій де формування поливних вод в басейні річки Інгулець залежить від впливу Криворізького залізорудного басейну розташованого в басейні річки. Скиди високомінералізованих шахтних вод в річковий басейн призводять до зміни швидкості течії у річці з 4 м³/сек до 20 м³/сек , що негативно впливає на життєві умови флори і фауни. Залежно від хімічного складу скидів змінюється мінералізація поливної води від 1,393 г/дм³ до 1,7608 г/дм³, а іноді досягає 4,349 г/дм³. За хімічним складом поливна вода формується як гідрокарбонатно-сульфатно-хлоридна при майже однаковому вмісту сульфатів та хлоридів, кальцієво-магнієво-натрієва зі значною перевагою натрію. Динаміка показників якості поливної води протягом 2013-2021 років свідчить про зростання найбільш небезпечних для ґрунтів показників: водневого показника ґрунтового розчину (pH) від 7,7 до 8,4, вмісту іонів хлору (Cl^-) – від 9,52 до 10,77 мекв/дм³ та натрію (Na^+) – від 9,52 до 13,33 мекв/дм³. За допомогою кореляційного і регресійного аналізів виявлені закономірності формування гідрохімічного складу води і встановлено сильний функціональний зв'язок між мінералізацією та іонами хлору (r = 0,99) та сульфат-іонами (r = 0,99), між мінералізацією та гідрокарбонат-іонами (r = 0,47). В міру підвищення мінералізації води пропорційно зростає вміст іонів хлору та сульфат-іонів, гідрокарбонат-іони відіграють другорядну роль у формуванні гідрохімічного складу. Доведено, що для запобігання перевищення іонів хлору більше 350 мекв/дм³ та сульфат-іонів – 500 мекв/дм³ мінералізація зрошувальної води не повинна перевищувати 1500 мг/дм³, а для запобігання перевищення іонів хлору більше 350 мекв/дм³ витрати води із каналу повинні бути не менш 9,0 м³/с.

Ключові слова*: мінералізовані води, поливна вода, осолонцювання, агромеліоративні заходи, меліорація ґрунтів, регламент промивки.*

Внесок авторів: Грановська Л. – кореляційно-регресійний аналіз та узагальнення результатів; Морозов О. – математичне моделювання; Писаренко П. – експериментальні дослідження, аналіз результатів; Вожегов С. – експериментальні дані, аналіз результатів

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