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Prevention of degradation processes of soils irrigated with mineralized water through plastering

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Abstract. The long-term irrigation of extensive areas in the steppe zone of Ukraine using low-quality and mineralized water has caused degradation processes associated with soil salinization. To mitigate or alleviate these processes, researchers investigated the potential of chemical reclamation through the application of phosphogypsum. The study took place in the northern Steppe of Ukraine near the village of Oleksandrivka, Dnipro district, Dnipropetrovsk region. Over many years, field experiments were conducted, introducing phosphogypsum as a chemical meliorant. The experimental design included the application of phosphogypsum at rates of 1.4, 3.0, and 6.0 t/ha during different periods of the year. Standardized research methods were used for sampling, laboratory analysis, and processing of the results. The research identified a high salt content (0.35-0.48%) in

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the arable soil layer, signs of salinization (exchangeable sodium content of 3.64%), and unsatisfactory physical condition of the soil in the research areas. The application of phosphogypsum led to an increase in sulfate anions, as observed in the soil's sulfate chemistry, while the control areas exhibited a soda-sulfate type of salinity. The pH level of the water extract remained within neutral values throughout the years of the study. Positive changes were observed regarding the degree of soil salinity. Specifically, the application of phosphogypsum at rates of 3 and 6 t/ha in irrigated areas resulted in a change from moderate to slightly saline salinity levels. The research also demonstrated a positive effect on the sodium-adsorption ratio, particularly when phosphogypsum was applied during irrigation in the third year. The sodium-adsorption ratio decreased by 69% compared to the control options, indicating a better ameliorative effect of phosphogypsum during irrigation. Under the conditions of using water of class II quality for irrigation, the optimal application of phosphogypsum was found to be at doses of 3 t/ha for spring cultivation and 6 t/ha for the main cultivation in autumn. These application rates effectively reduced the degree of soil salinity and improved the ecological and meliorational conditions of the irrigated area

Keywords: land reclamation; irrigation; salinization; phosphogypsum; sodium-adsorption ratio; degree of salinity

INTRODUCTION

In contemporary agricultural practices, achieving reliable and consistent crop yields is unattainable without irrigation. While irrigation plays a vital role in enhancing agricultural productivity, it can also trigger unfavorable soil degradation processes. Prolonged irrigation with subpar water quality induces long-lasting alterations in the physical and mechanical properties of soils, as well as their salt composition.

Starting from the previous century, hydrotechnical land reclamation has been developed in Ukraine, resulting in about 5.5 million hectares of reclaimed land, with over 2.2 million hectares currently irrigated. However, due to inadequate exploitation, insufficient funding, and aging infrastructure, as of 2021, only 0.6 million hectares were irrigated. The long-term irrigation of large areas in the southern region of Ukraine with deteriorating water quality for more than 50-70 years caused soil degradation through salinization (Chornyy & Isaeva, 2023). To restore the meliorative systems and produce high-quality agricultural products, it is necessary to improve the ecological and meliorative state of irrigated soils. One potential solution to limit or mitigate the negative effects of salinization is to investigate the use of phosphogypsum in chemical reclamation, which is the focus of the research presented in the article.

The world practice of irrigation with mineralized surface and underground waters has shown that such irrigation is always accompanied by salinization of soils, leads to deterioration of their physical properties and a significant decrease in fertility. The use of gypsum as a chemical meliorant during irrigation with mineralized water is a long-known technique in the practice of irrigated agriculture, which is covered in many scientific works (McKenna *et al.*, 2019; Makarova *et al.*, 2021).

In Ukraine, studies on plastering of soils irrigated with mineralized waters were conducted by various scientists (Menshov & Kruglov, 2023). As a result of these studies, it was established that melioration by plastering increases the content of exchangeable and absorbed calcium and significantly reduces the amount of absorbed sodium. But even with high doses of gypsum, it is not possible to bring the degree of the soil solution saturation with calcium to the required level in the absence of watering. Ukrainian scientists, European and Asian researchers established patterns of changes in soil properties under the influence of irrigation and developed techniques to mitigate the adverse impact of poor-quality irrigation water on soils (Cuevas *et al.*, 2019; Baliuk *et al.*, 2021). Plastering and deep plantation plowing remain the most studied. Moreover, it was emphasized that plastering is a technique that limits or weakens the process of salting, but does not eliminate it completely (Bello *et al.*, 2021)

Considering numerous scientific studies in the field of chemical melioration of irrigated soils and water, this problem remains insufficiently studied and relevant. Questions about the expediency and effectiveness of plastering chernozems with a weak degree of salinization remain unresolved. There are objections to the approaches to calculating doses of ameliorants and the quantitative component of the interaction of gypsum with soil and water is insufficiently covered. The ecological aspects of the ameliorants use have not been well developed, which necessitates the search for new, more effective measures from the point of view of resource and energy saving and environmental safety (Tsapko *et al.*, 2017).

The need for chemical reclamation of irrigated lands is due to salinization of soils and their degradation –

compaction, destructuring, crust formation, etc. (Filipciuc *et al*., 2019). Irrigation with water of inadequate quality and non-compliance with the ecological components of farming cause the processes of soil degradation and the deterioration of the ecological and meliorative state of agricultural landscapes (Rudakov *et al*., 2020; Andrieiev *et al*., 2022; Hapich *et al*., 2023). Unfounded regimes of chernozem soils irrigation lead to negative processes associated with excessive accumulation of harmful salts in the upper layer of the soil, acidification, raising the level of groundwater, over-compaction, etc. These processes encourage further research into the agromelioration state of irrigated soils when irrigated with water that is limited in use (Rudakov & Hapich, 2019).

The effect of chemical ameliorants is to squeeze out, or create an obstacle for the entry of sodium into the soil absorption complex, due to which the physical properties of the soil change in the direction of a favorable regime for increasing the productivity of agricultural crops. Due to the displacement of the soil absorption complex of sodium by calcium or other two- or three-charged cations, the mobility of soil colloids decreases, the content of nutrients (N, P, K) increases, alkalinity decreases, and microbiological processes in the soil are activated (Syed *et al*., 2021).

According to the results of scientific research conducted in the conditions of the Northern Steppe of Ukraine, the peculiarities of the degradation processes occurring in irrigated soils were established, which are determined by the quality of irrigation water, initial physical properties of soils, anti-saline buffering capacity, depth of occurrence and mineralization of groundwater (Makarova *et al*., 2020).

Analyzing modern scientific publications, we can conclude that in order to save resources and increase efficiency, chemical land reclamation should be based on new conceptual provisions, namely: in the first place, soils with a medium and strong degree of salinity are subject to land reclamation; it is necessary to introduce ameliorants into the soil in the form of a solution or suspension, as well as locally along the contours of saline soils in periods of maximum salinity; application in a complex of hydrotechnical, chemical and agrotechnical land reclamation on irrigated soils (Cuevas *et al*., 2019; Syed *et al*., 2021).

The object of research are soils irrigated for 50 years, and the processes of changing their fertility indicators depending on the dose of phosphogypsum application.

The subject of research is the change in the chemical composition of the water extraction of irrigationally saline soils when using phosphogypsum as a chemical ameliorant.

The purpose of the research was an ecological improvement assessment of the state of irrigated soils, as well as the improvement of existing measures to reproduce the fertility of salinized irrigated soils by applying different doses of phosphogypsum. To accomplish the intended objective, several tasks need to be addressed, including: 1) scrutinizing the global and Ukrainian practices of utilizing phosphogypsum to ameliorate saline and salinized soils; 2) conducting a sequence of experiments under varying doses, durations, and conditions of implementing the ameliorant; 3) substantiating the ideal technological guidelines for employing phosphogypsum to deter soil degradation processes in areas irrigated with mineralized waters.

MATERIALS AND METHODS

To solve the main tasks proposed in this scientific work, the methods used in existing research were analyzed through a systematic approach to solving the problem of improving the ecological condition of irrigated lands. Methods of analysis and synthesis were used to establish the optimal method of combating soil salinization; conducted experimental studies in field and laboratory conditions. Field experiments were conducted to study the effect of chemical reclamation on the physical properties of the soil, and laboratory experiments were conducted to determine the physical and chemical properties of the soil and meliorants. Statistical methods were used to assess the reliability of the obtained research results. All research was conducted in compliance with current ethical and environmental standards (Law of Ukraine No. 962-IV, 2003; Thompson, 2017).

The research was provided in 2010-2021 near the village of Oleksandrivka on the territory of the Experimental Farm of the Dnipro Experimental Station of the Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences of Ukraine, in the Dnipro district of the Dnipropetrovsk region. The experimental fields of this farm are located near a lake on the Samara River, and field experiments were conducted on an area of 60 hectares, which is shown in Figure 1.

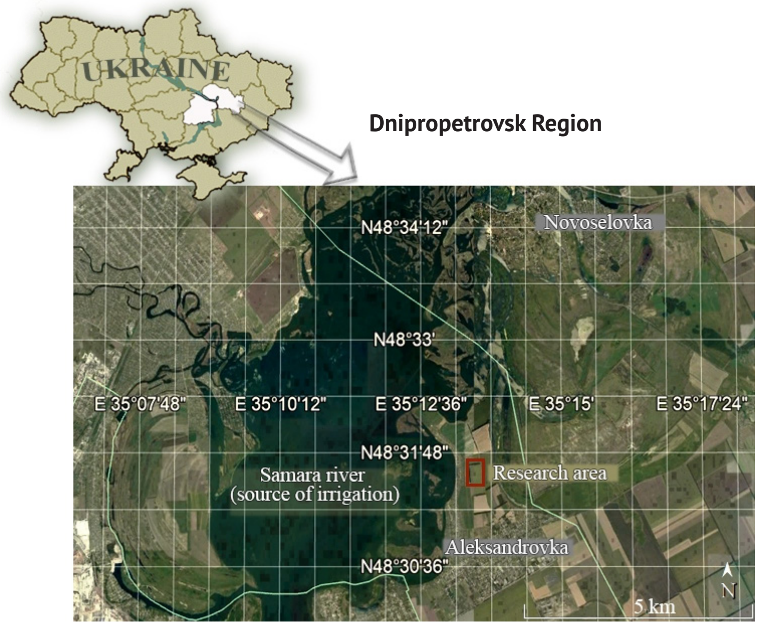

***Figure 1**. The place of research*

***Source:** developed by the authors based on data from the Google Earth Pro service*

The experimental plots are represented by ordinary chernozem, and the parent rock is loam loess, as evidenced by agrochemical and physical-mechanical indicators. The soils are classified as low-humus, as the content of the organic part reaches 2.5% (in the arable layer of the soil), and at a depth of 105 cm, its content is only 0.3%.

The hydrogen index of the soil in the experimental areas is in the range of 6-7.5. The total amount of toxic salts is 0.35-0.48%. In the soil absorption complex, the percentage content of exchangeable sodium is 3.64% with an absorption capacity of 23.29 meq per 100 g of soil. The salt composition of the soil and the content of the soil-absorbing complex indicate the development of salinization processes with a medium degree of salinity. According to N.A. Kachynskyi (Kovda, 1979) the granulometric composition of the soil belongs to light loam, since the arable layer contains 72.51% of physical sand, and 27.49% of physical clay. The mineralization of groundwater reaches 15 g/l with a depth of up to 5 m.

These soils on the experimental site were watered for 50 years with mineralized water (more than 2 g/l) from the Samara River. During vegetation watering with mineralized water, the soil swells, becomes plastic, viscous, sticky and peptized. With this unsatisfactory physical and chemical condition, the drying soil quickly compacts and becomes impermeable.

Unsatisfactory physical and mechanical condition of the soils in the experimental areas is a cause for concern, so it became necessary to study it. many years of field experiments to choose ways to improve and eliminate salinization have been established. It was also planned to monitor the physical and mechanical indicators and the chemical composition of the water extract of the soil, to control the quality of irrigation during the period of observation.

Climatic conditions during the years of research were characterized by a hydrothermal coefficient of 0.95-3.52. With regard to weather conditions, precipitation fell extremely unevenly, mainly in the hot season and had a rather intense nature, which created a small supply of moisture for the growth and development of agricultural crops. The extreme change in air temperature during the years of research also did not increase the reserves of available moisture in the soil. Irtek sprinkler hose-drum machine was used for watering.

To improve the quality of ordinary salted chernozem, a calcium-containing ameliorant from a by-product of the mineral fertilizers production (phosphogypsum) was chosen.

The research scheme is shown in Table 1. According to the proposed recommendations, phosphogypsum was applied as a reserve for 3 years with and without irrigation.

***Table 1**. The field research scheme*

Conditions for providing moisture	Norm/methodology for calculating the application of phosphogypsum	Variant
Without irrigation	without adding phosphogypsum (control)	V1
	introduction of phosphogypsum under cultivation in the spring at the rate of 1.4 t/ha / Pfeffer's method as modified by Molodtsov, Ignatova, 1990	V3

Table 1, Continued

Conditions for providing moisture	Norm/methodology for calculating the application of phosphogypsum	Variant
Without irrigation	introduction of phosphogypsum under cultivation in the spring at the rate of 3 t/ha / O.M. Grinchenko method, 1980	V4
	introduction of phosphogypsum in the fall under the main tillage at the rate of 6 t/ha / the method of B.I. Laktionov, 1963	V5
With irrigation	without adding phosphogypsum (control)	V2
	introduction of phosphogypsum under cultivation in the spring at the rate of 1.4 t/ha / Pfeffer's method as modified by Molodtsov, Ignatova, 1990	V6
	introduction of phosphogypsum under cultivation in the spring at the rate of 3 t/ha / O.M. Grinchenko method, 1980	V7
	introduction of phosphogypsum in the fall under the main tillage at the rate of 6 t/ha / the method of B.I. Laktionov, 1963	V8

Source: *developed by authors based on O.V. Morozov et al. (2008)*

The established norms were determined according to the methods of calculation of ameliorative, agronomic and ecologically safe doses of phosphogypsum application. None of the calculated doses exceeded 10 t/ha, which is environmentally safe for this locally produced phosphogypsum.

The chemical composition of the aqueous extract of the soil (anion-cation content) characterizes its salinity type. To establish the chemistry of salinization, preference was given to negatively charged particles of the arable layer of the soil (30 cm) (Instruction of the State..., 2002).

All analyses were carried out in certified laboratories in Dnipro in accordance with the regulatory and methodological base in force in Ukraine (DSTU ISO 10390:2022, 2022; DSTU ISO 11260-2001, 2003; DSTU ISO 8466-1-2001, 2003; DSTU 7912:2015, 2016).

RESULTS AND DISCUSSION

Dnipropetrovsk region is characterized by a high percentage of arable land in agricultural land. Modern climatic features encourage the use of irrigation as the main intensifier of production. This causes uncontrolled irrigation both in terms of norms and quality of irrigation water. Previous experiments proved that watering with water suitable for irrigation can also have a negative effect on the physical, mechanical and other properties of soils (Makarova *et al.*, 2020). As for water that is limited for irrigation, its influence on the salt and exchange composition of the soil is much stronger compared to irrigation with fresh water. As a result of long-term irrigation with water of different quality in the territory of the Northern Steppe of Ukraine, an acute problem of secondary salinization and salting of lands arose. A change in the natural state leads to the degradation of soils, their removal from their intended purpose due to the loss of fertility (Onopriienko *et al.*, 2019).

As a result of the investigations, the anionic-cationic composition of the aqueous extract of the arable layer of the soil was determined in all experimental areas. The results of the average indicators of water extract analyzes for soil anions and cations in mEq/100 g of soil in the experimental areas are shown in Table 2.

Table 2. *Indicators of soil water extraction in the first three years of research*

Research variant	A year after the effect of phosphogypsum	Hydrogen index	Anionic composition, meq/100 g of soil			Cation composition, meq/100 g of soil			Sodium-adsorption ratio
			hydrocarbons	chlorides	sulfates	calcium	magnesium	sodium	
V1	first	7.4	0.324	0.99	2.306	0.621	0.58	2.42	3.12
	second	7.2	0.59	0.7	2.507	0.597	0.49	2.71	3.68
	third	7.4	0.348	0.897	2.421	0.573	0.47	2.623	3.63
V2	first	7.5	0.22	1.215	2.990	0.253	0.156	4.016	8.87
	second	7.4	0.575	1.248	2.75	0.313	0.278	3.982	7.33
	third	7.5	0.34	1.27	2.65	0.32	0.284	3.656	6.65
V3	first	7.17	0.169	1.158	3.17	0.73	0.363	3.404	4.61
	second	6.7	0.546	0.987	2.788	0.7	0.424	3.197	4.26
	third	7.2	0.28	1.198	2.694	0.678	0.395	3.104	4.24

Table 2, Continued

Research variant	A year after the effect of phosphogypsum	Hydrogen index	Anionic composition, meq/100 g of soil			Cation composition, meq/100 g of soil			Sodium-adsorption ratio
			hydrocarbons	chlorides	sulfates	calcium	magnesium	sodium	
V4	first	7.29	0.297	1.095	3.299	1.024	0.628	3.039	3.34
	second	6.89	0.486	1.0	2.8	1.0	0.395	2.891	3.46
	third	7.26	0.273	1.098	2.776	0.987	0.401	2.76	3.31
V5	first	7.37	0.289	1.122	3.325	1.56	0.687	2.488	2.35
	second	6.97	0.256	0.879	3.0	1.478	0.364	2.292	2.39
	third	7.34	0.258	0.898	2.845	1.425	0.389	2.188	2.30
V6	first	7.22	0.318	0.982	2.742	1.124	0.520	2.398	2.64
	second	6.75	0.48	0.627	2.7	1.1	0.45	2.257	2.56
	third	7.21	0.315	0.85	2.521	1.092	0.366	2.228	2.61
V7	first	7.36	0.37	0.898	3.038	1.579	0.427	2.3	2.30
	second	6.91	0.434	0.621	3.019	1.52	0.465	2.089	2.10
	third	7.3	0.291	0.856	2.764	1.489	0.42	2.002	2.05
V8	first	7.43	0.369	0.876	3.424	2.157	0.267	2.246	2.04
	second	7.0	0.567	0.612	3.366	2.1	0.477	1.968	1.73
	third	7.38	0.249	0.797	3.175	2.0	0.439	1.782	1.61

Source: *developed by authors*

On the control option where irrigation was carried out (V2), a tendency to decrease SO_4^{-2} ion indicators was observed, which is explained by the leaching of sulfates together with irrigation water. On the contrary, an increase in sulfates by 0.20 mEq/100 g of soil in the second year, compared to the first, and a further decrease in their amount in the third year were seen on the control plots without irrigation. The second year of research was characterized by increased air temperature compared to the average long-term values, which, as it is supposed, caused the arrival of sulfates from the lower layers of the soil profile during this period of research.

The anionic indicators of the aqueous extraction of the soil (Table 2) were marked by an increase in the amount of SO_4^{-2} compared to the control option where irrigation was not carried out and phosphogypsum was not applied during the entire period of research. The average annual amount of SO_4^{-2} ions in the irrigated options during the observation period increased by 15-18% compared to the non-irrigated control options of the experiments.

This fact can be explained by the ingress of SO_4^{-2} ions into the arable layer of the soil together with irrigation water. This is confirmed by the results of the observations, since the number of SO_4^{-2} ions was significantly lower in the control variants in the absence of irrigation. The exception was the second year of observations, in which the amount of sulfates was the highest – 2.51 meq/100 g of soil.

The maximum concentration of SO_4^{-2} (V8, Table 2) was obtained in the irrigated areas with the introduction of the largest dose of phosphogypsum compared to the control areas without irrigation with the use of phosphogypsum. According to the data in this table, the average annual indicators of SO_4^{-2} concentration are 3.18-3.43 mEq/100 g of soil, which is 0.87-0.92 mEq/100 g of soil more than the control options without irrigation. Application of phosphogypsum in different doses on irrigated areas (V6, V7, V8) led to the accumulation of SO_4^{-2} ions in proportion to the increase in the dose of its application. Analyzing the changes in the number of sulfate ions in these variants of the experiments, according to the years of research, a pattern of decreasing SO_4^{-2} ions was observed to 2.5 meq/100 g of soil (V6), to 2.8 meq/100 g of soil (V7) and to 3.2 meq/100 g of soil (V8) in the third year (Table 2).

A tendency to increase the content of sulfate ions was observed in variants with phosphogypsum when irrigated compared to the non-irrigated control. Comparing the two control options (with and without irrigation) and options with phosphogypsum application during irrigation, an increase in average annual SO_4^{-2} ions by 0.42 meq/100 g of soil was observed. In areas where phosphogypsum was applied without irrigation, the content of SO_4^{-2} ions increased when the dose of phosphogypsum application was increased. At a dose of phosphogypsum application of 1.4 t/ha, there were 3.17 meq/100 g of soil sulfate, while at a dose of 6 t/ha – 3.33 meq/100 g of soil in the first year after the action. During the years of the meliorative effect, the amount of sulfate ion gradually decreased by an average of 15% in the third year after the effect. Compared to the control irrigated options, the content of SO_4^{-2} ions increased by only 0.42 meq/100 g of soil with the introduction of a dose of phosphogypsum of 6 t/ha during irrigation, while at lower doses such a trend was not observed. For doses of phosphogypsum application of 6 t/ha during irrigation in the third year, the content of sulfate ions also increased by 0.53 meq/100 g of soil compared to the control plots. This is explained by the arrival of SO_4^{-2} ions with mineralized irrigation water and their content in phosphogypsum. The gradual decrease in the number of ions in the third year after the application of phosphogypsum is explained by the removal of the formed sodium sulfate into the lower soil horizons (Onopriienko *et al*., 2019)

During the research period, no corresponding dependence was observed in the change in the amount of HCO_3^{-1}. An insignificant decrease in the content of hydrocarbons was noted in the areas where irrigation was carried out and different amounts of phosphogypsum were applied. The absence of watering and phosphogypsum in the experimental areas led to an increase in the content of HCO_3^{-1} ions.

In the areas where irrigation was carried out and phosphogypsum was applied in relation to the control irrigated areas, the content of HCO_3^{-1} ions differed by 0.04-0.06 meq/100 g of soil according to the average annual values. On the control plots without irrigation, up to 0.07 meq/100 g of soil more hydrocarbons were noted in comparison with variants V3, V4 and V5 where phosphogypsum was applied, but without irrigation.

The content of HCO_3^{-1} ions in the water extract of the soil did not show a clear dependence on the dose of phosphogypsum application. In the areas where irrigation was carried out and without irrigation, the highest concentration of hydrocarbons was obtained at a dose of phosphogypsum application of 3 t/ha. The highest value of this ion content was recorded in the second year after the action in the options where irrigation was carried out (V6) – 0.567 meq/100 g of soil, as well as in the areas without irrigation (V3) – 0.55 meq/100 g of soil.

During the research, the dependence of irrigation on the increase in the concentration of Cl ions in the soil was established. In the experiments, chlorides entered the soil only during irrigation with mineralized water. The content of Cl ions increased by one and a half times when irrigated with water from the Samara River compared to non-irrigated control variants. Application of phosphogypsum and irrigation compared to the control options without irrigation reduced the chloride content in the soil by 34%. The lack of irrigation due to the introduction of phosphogypsum did not affect the change in the concentration of chlorine ions. In the control plots during the research years, this indicator was 0.86 meq/100 g of soil. When applying phosphogypsum at a dose of 1.4 t/ha, the content of chlorine ions was 1.11 meq/100 g of soil, and at doses of 3 and 6 t/ha – 1.0 meq/100 g of soil.

The amount of chlorine ions did not depend on the dose of phosphogypsum during the entire period of research. In the absence of irrigation after the application of phosphogypsum, the lowest indicators of chloride content were noted in the second year after the action at a dose of phosphogypsum application of 6 t/ha, which is 10% lower than the application dose of 1.4 t/ha. This tendency was also preserved in the irrigated areas with the introduction of phosphogypsum, only with a decrease in the total content of chlorides by 35-48% compared to the control irrigated options. This regularity is explained by the redistribution of chlorine anions to sulfate ions.

The type of soil salinity was determined by the ratios of the maximum values of the content of anions-cations, the results of which are shown in the Table 3. According to the chemical composition of the anionic component of the water extract of the soil from the experimental plots, the sulfate type of salinization was established in variants with phosphogypsum on irrigated and non-irrigated plots. In the control variant (V1), the soda-sulfate type was installed only in the first year of observations. In the future, on this variant, self-improvement of non-irrigated soil changed the chemistry to sulfate. By combining anions and cations into hypothetical molecules of the appropriate amount (meq/100 g of soil), the degree of salinity equivalent to chlorine and the amount of toxic salts in percent were determined for all variants of experiments.

Table 3. *Type and degree of soil salinization*

Research variant	Degree of salinity/chemism (type) of salinity	A year of research		
		first	second	third
V1	The degree of salinity is equivalent to Cl, meq	0.61	1.39	0.76
	$S_{tox.\ salts}$, %	0.21	0.32	0.29
	Chimism (type)	sodium sulfate	sodium sulfate	sodium sulfate
V2	The degree of salinity is equivalent to Cl, meq	1.39	1.69	1.99
	$S_{tox.\ salts}$, %	0.3	0.35	0.36
	Chimism (type)	sodium sulfate	sodium sulfate	sodium sulfate

Table 3, Continued

Research variant	Degree of salinity/chemism (type) of salinity	A year of research		
		first	second	third
V3	The degree of salinity is equivalent to Cl, meq	1.39	1.49	1.63
	$S_{tox. salts}$, %	0.37	0.38	0.35
	Chimism (type)	sodium sulfate	sodium sulfate	sodium sulfate
V4	The degree of salinity is equivalent to Cl, meq	1.39	1.52	1.96
	$S_{tox. salts}$, %	0.39	0.39	0.37
	Chimism (type)	sodium sulfate	sodium sulfate	sodium sulfate
V5	The degree of salinity is equivalent to Cl, meq	1.7	1.62	1.88
	$S_{tox. salts}$, %	0.4	0.38	0.38
	Chimism (type)	sodium sulfate	sodium sulfate	sodium sulfate
V6	The degree of salinity is equivalent to Cl, meq	1.6	1.51	1.75
	$S_{tox. salts}$, %	0.58	0.41	0.4
	Chimism (type)	sodium sulfate	sodium sulfate	sodium sulfate
V7	The degree of salinity is equivalent to Cl, meq	1.5	1.41	1.56
	$S_{tox. salts}$, %	0.42	0.41	0.4
	Chimism (type)	sodium sulfate	sodium sulfate	sodium sulfate
V8	The degree of salinity is equivalent to Cl, meq	1.5	1.48	1.48
	$S_{tox. salts}$, %	0.41	0.41	0.41
	Chimism (type)	sodium sulfate	sodium sulfate	sodium sulfate

Source: *developed by authors*

According to FAO standards (1988), the degree of soil salinization depends on the sodium-adsorption ratio (SAR). In a particular case, based on the received cation indicators, SAR values were obtained in the first three years of research, the values of which are shown in Figure 2.

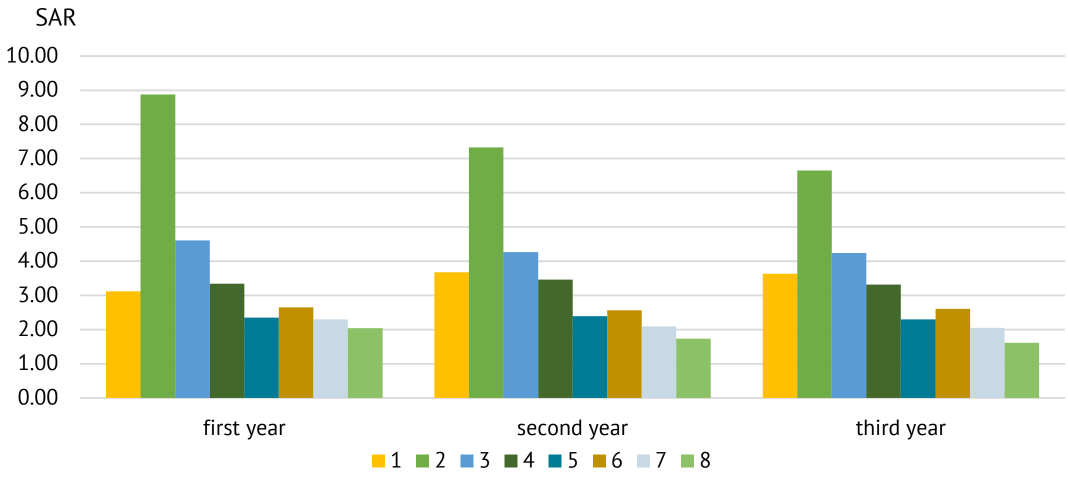

Figure 2. *Indicators of the SAR according to research options in the years of research*

Source: *developed by authors*

It was established that the degree of soil salinity depends on the values of the pH and SAR indicators, and for all variants of research it is characterized as slightly saline, and for the first variant of experiments (V1) salinity is characterized by an average degree. Analyzing the indicators of the control plots in the variant without irrigation, an increase in the SAR indicator by 0.56 units was observed in the second year. This trend also occurred with SO_4^{-2} ions. This indicates the influx of sodium sulfate from the lower layers of the soil profile into the arable layer during this period.

The change in the SAR indicator in the third year after the effect of chemical reclamation at a depth of 0-105 cm (Fig. 2) is characterized by minimal indicators.

The effective indicators of SAR reduction correspond to options where mineralized water was irrigated and phosphogypsum was applied at doses of 3 and 6 t/ha, as well as without irrigation, where phosphogypsum was applied at the recommended dose of 6 t/ha.

The restructuring of the water management sector, particularly in agricultural irrigation reclamation, has resulted in reduced funding and the cessation of reclamation science development. This is exemplified by a substantial decline in scholarly works on the topics of reclamation soil science and the effects of irrigation water quality on soils, despite the necessity of these studies being undisputed among experts. The most recent fundamental research conducted in Ukraine regarding these concerns is a decade or more old, and the quality of both irrigation water and water resources in general continues to deteriorate, a trend that is also observable globally (Kuzminskyi & Natalchuk, 2004).

The research conducted by R.O. Babushkina (2006) reports the outcomes of a study examining the impact of chemical land reclamation (limestone applied at rates of 5, 10, and 15 t/ha and phosphogypsum applied at rates of 12, 24, and 36 t/ha) and irrigation on the primary physical and physicochemical properties of black soil that is typically found in the irrigated regions of southern Ukraine. O. Nosonenko *et al*. (2022) have established the patterns of the effect of various doses of gypsum on the physicochemical and saline indicators of slightly saline dark-chestnut soil in the Kherson region. In contrast to the above-mentioned soil types, which are dark-chestnut and southern chernozems, research has focused less on the effectiveness and techniques of calcium ameliorant application on ordinary chernozems. Questions pertaining to the feasibility and efficacy of using gypsum on chernozems with mild degrees of salinization are still debatable, and there is a lack of defined approaches for calculating ameliorant dosages, insufficiently clarified quantitative indicators for the interaction between gypsum, soil, and irrigation water, and poorly developed ecological aspects of using chemical ameliorants. The issues surrounding the chemical reclamation of irrigated chernozems, which are frequently affected by salinization due to the use of Class I and II waters for irrigation, and their subsequent degradation (e.g. compaction, destructuring, and crust formation), remain unresolved.

All anions and cations contained in the water extract of the soil are bound into the corresponding chemical compounds. Some obtained compounds have a negative effect on the growth of plants and their physiological state. Such chemicals include compounds of carbonates and chlorides. Chlorides slow down plant growth and are toxic substances for most agricultural crops, for example, for corn (Cui *et al*., 2019). Na_2SO_4 ions can also be a restraining factor in the development of some plants, but this substance dissolves very well in water and contains sulfur, which takes part in redox reactions, the creation of protein molecules, energy exchange and is a building material for plant cells (Peng *et al*., 2008).

Therefore, one of the elements that should be incorporated into the revitalization (restoration) system of hydrotechnical reclamation is the study of issues related to the improvement of the ecological and reclamation state of soils and its impact on the production of high-quality agricultural products.

CONCLUSIONS

Studies have shown that the introduction of phosphogypsum as a chemical ameliorant on irrigated saline chernozems improves the anion-cation composition of water extract and the degree of soil salinity. In all versions of the experiments, according to the cationic composition of the aqueous extract of the soil, the sodium type of salinization was established. Remedial measures by applying phosphogypsum under irrigation conditions change the anionic composition of the soil aqueous extract in the direction of increasing sulfate ions, which characterizes the sulfate chemistry of the soil. In the absence of irrigation and without the introduction of phosphogypsum, the soils had a soda-sulfate type of salinity.

The reaction of the soil solution during the years of observation was close to neutral (6.7-7.9). The degree of soil salinity in the experimental areas was determined by the "total effect" of hypothetically bound toxic ions. The variants of experiments with the application of phosphogypsum at the rate of 3 and 6 t/ha during irrigation, where the degree of salinity changed from medium to slightly saline, responded best. The SAR in the third year after the application of phosphogypsum in relation to the control parameters without irrigation decreased by 10%. Application of phosphogypsum and irrigation of vegetation in the third year after the effect led to the best results, that is, there was a decrease in SAR indicators in relation to the control variants by 69%. This confirms the theory of increased ameliorative effect of phosphogypsum under irrigation conditions.

Based on the SAR value, the degree of salinity of the experimental plots was characterized as a weakly saline type in the variants with phosphogypsum application, and moderately saline in the control variant with irrigation. According to the SAR indicators, the best options for irrigation with water of the II quality class were the doses of phosphogypsum for cultivation in the spring – 3 t/ha and in the fall for the main tillage – 6 t/ha.

Future scientific research should be based on a comprehensive approach to solving optimization problems related to chemical melioration of irrigation water, introducing calcium meliorants into the soil as a solution or suspension, local application along the contours of saline soils during periods of maximum physical salinity manifestation, resource and energy conservation, deep meliorative tillage on irrigated soils, and cultivation of moisture-loving, high-yielding, and saline-resistant crops.

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CONFLICT OF INTEREST

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REFERENCES

[1] Andrieiev, V., Hapich, H., Kovalenko, V., Yurchenko, S., Pavlychenko, A. (2022). Efficiency assessment of water resources management and use by simplified indicators. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 5, 148-152. doi: 10.33271/nvngu/2022-5/148.

[2] Babushkina, R.O. (2006). *Agromelioration effectiveness of the use of calcium-containing meliorants on irrigated southern chernozems*. (Doctoral dissertation, Kherson State Agrarian University, Kherson, Ukraine).

[3] Baliuk, S.A., Kucher, A.V., & Maksymenko, N.V. (2021). Soil resources of Ukraine: State, problems and strategy of sustainable management. *Ukrainian Geographical Journal*, 2, 3-11. doi: 10.15407/ugz2021.02.003.

[4] Bello, S.K., Alayafi, A.H., AL-Solaimani, S.G., & Abo-Elyousr, K.A.M. (2021). Mitigating soil salinity stress with gypsum and bio-organic amendments: A review. *Agronomy*, 11(9), 1735. doi: 10.3390/agronomy11091735.

[5] Chornyy, S.G., & Isaeva, V.V. (2023). Salinisation of chernozem soils by brackish irrigation water in Southern Ukraine. *International Journal of Environmental Studies*, 80(2), 421-432. doi: 10.1080/00207233.2023.2192116.

[6] Cuevas, J., Daliakopoulos, I.N., del Moral, F., Hueso, J.J., & Tsanis, I.K. (2019). A review of soil-improving cropping systems for soil salinization. *Agronomy*, 9(6), 295. doi: 10.3390/agronomy9060295.

[7] Cui, W., Kamran, M., Song, Q., Zuo, B., Jia, Z., & Han, Q. (2019). Lanthanum chloride improves maize grain yield by promoting photosynthetic characteristics, antioxidants enzymes and endogenous hormone at reproductive stages. *Journal of Rare Earths*, 37(7), 781-790. doi: 10.1016/j.jre.2018.12.006.

[8] DSTU 7912:2015. (2016). *Soil quality. The method of determination of exchangeable sodium*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=62775.

[9] DSTU ISO 10390:2022. (2022). *Soil, processed biowaste and sediments. Determination of pH (ISO 10390:2021, IDT)*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page.html?id_doc=97744.

[10] DSTU ISO 11260-2001. (2003). *Soil quality. Determination of cation exchange capacity and base saturation using barium chloride solution (ISO 11260:1994, IDT)*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=57138.

[11] DSTU ISO 8466-1-2001. (2003). *Water quality. Determination of grading characteristics of methods of quantitative chemical analysis (ISO 8466-1:1990, IDT)*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=66580.

[12] FAO. (1988). *Saline soils and their management*. Retrieved from https://www.fao.org/3/x5871e/x5871e04.htm.

[13] Filipciuc, V., Rozloga, I., Cojocaru, O., & Boaghe, L. (2019). Study of pedogenetic processes in soils long irrigated-monitoring and projecting their evolution. *Scientific Papers. Series A. Agronomy*, 62(1), 48-55. Retrieved from https://agronomyjournal.usamv.ro/pdf/2019/issue_1/Art7.pdf.

[14] Hapich, H.V., Orlinska, O., Pikarenya, D., Chushkina, I.V., Pavlychenko, A.V., & Roubík, H. (2023). Prospective methods for determining water losses from irrigation systems to ensure food and water security of Ukraine. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 2, 154-160. doi: 10.33271/nvngu/2023-2/154.

[15] Instruction of the State Committee of Ukraine for Water Management "For carrying out soil and salt surveys on irrigated lands of Ukraine". (2002, August). Retrieved from https://ep3.nuwm.edu.ua/2767/1/nd086%20zah.pdf.

[16] Kovda, V.A. (1979). To combat salinization of fertile soils – an editorial. *Climatic Change*, 2(2), 103-108. doi: 10.1007/BF00133217.

[17] Kuzminskyi, V.V., & Natalchuk, A.M. (2004). Research on land reclamation and irrigation water quality. *Land Reclamation and Water Management*, 90, 50-62.

[18] Law of Ukraine No. 962-IV "On Land Protection". (2003, June). Retrieved from https://zakon.rada.gov.ua/laws/show/962-15#Text.

[19] Makarova, T., Domaratskiy, Ye., Hapich, G., & Kozlova, O. (2021). Agromeliorative efficiency of phosphogypsum application on irrigation saline soils in the Northern Steppe of Ukraine. *Indian Journal of Ecology*, 48(3), 789-795. Retrieved from https://dspace.dsau.dp.ua/handle/123456789/5220.

[20] Makarova, T., Maksymova, N., Hapich, G., & Chushkina, I. (2020). Redistribution of particle-size fractions in ordinary chernozem affected by long-term irrigation and chemical melioration with phosphogypsum. *Land Reclamation and Water Management*, 1, 95-101. doi: 10.31073/mivg202001-238.

[21] McKenna, B.A., Kopittke, P.M., Macfarlane, D.C., Dalzell, S.A., & Menzies, N.W. (2019). Changes in soil chemistry after the application of gypsum and sulfur and irrigation with coal seam water. *Geoderma*, 337, 782-791. doi: 10.1016/j.geoderma.2018.10.019.

[22] Menshov, O., & Kruglov, O. (2023). Agricultural soil degradation in Ukraine. In P. Pereira, M. Muñoz-Rojas, I. Bogunovic, & W. Zhao (Eds.) *Impact of agriculture on soil degradation II* (pp. 325-347). doi: 10.1007/698_2022_951.

[23] Morozov, O.V., Bezuhlyi, O.P., & Shukailo, S.P. (2008). *Technology of chemical melioration of irrigation soil in the Kherson region: Scientific and methodical recommendations*. Kherson: Kolos.

[24] Nosonenko, O., Zakharova, M., Vorotyntseva, L., & Afanasiev, Yu. (2022). Effect of differentiation of doses of chemical improver on the indicators of halogenesis of dark-chestnut alkaline soil. *Bulletin of Agricultural Science*, 100(5), 12-19. doi: 10.31073/agrovisnyk202205-03.

[25] Onopriienko, D.M., Shepel, A.V., & Makarova, T.K. (2019). Influence of phosphogypsum on the chemical composition of aqueous extract from soil. *Agrology*, 2(3), 151-155. doi: 10.32819/019022.

[26] Peng, Y.-L., Gao, Z.-W., Gao, Y., Liu, G.-F., Sheng, L.-X., & Wang, D.-L. (2008). Eco-physiological characteristics of alfalfa seedlings in response to various mixed salt-alkaline stresses. *Journal of Integrative Plant Biology*, 50(1), 29-39. doi: 10.1111/j.1744-7909.2007.00607.x.

[27] Rudakov, L., Hapich, H., Orlinska, O., Pikarenia, D., Kovalenko, V., Chushkina, I., & Zaporozhchenko, V. (2020). Problems of technical exploitation and ecological safety of hydrotechnical facilities of irrigation systems. *Journal of Geology, Geography and Geoecology,* 29(4), 776-788. doi: 10.15421/112070.

[28] Rudakov, L.M., & Hapich, H.V. (2019). Modern state, dynamics of changes and prospects for the development of hydrotechnical reclamations in Dnipropetrovsk region. *Land Reclamation and Water Management*, 1, 54-60. doi: 10.31073/mivg201901-161.

[29] Syed, A., Sarwar, G., Shah, S.H., & Muhammad, S. (2021). Soil salinity research in 21st century in Pakistan: Its impact on availability of plant nutrients, growth and yield of crops. *Communications in Soil Science and Plant Analysis*, 52(3), 183-200. doi: 10.1080/00103624.2020.1854294.

[30] Thompson, P.B. (2017). *The spirit of the soil: Agriculture and environmental ethics*. New York: Routledge. doi: 10.4324/9781315559971.

[31] Tsapko, Y., Desyatnik, K., & Ogorodnya, A. (2017). Ecological reclamation of acid soils. In D. Dent, & Y. Dmytruk (Eds.) *Soil science working for a living* (pp. 175-180). Switzerland: Springer International Publishing. doi: 10.1007/978-3-319-45417-7_16.

Запобігання процесам деградації зрошуваних мінералізованими водами ґрунтів шляхом гіпсування

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Анотація. Тривале зрошення значних площ степової зони України неякісною та мінералізованою водою призвели до деградаційних процесів, пов'язаних із засоленням та осолонцюванням ґрунтів. Для обмеження або послаблення цих процесів досліджено можливість застосовування хімічної меліорації шляхом внесення фосфогіпсу. Дослідження проведені в умовах північного Степу України на дослідних ділянках, розташованих біля села Олександрівка Дніпровського району Дніпропетровської області. Були закладені багаторічні польові досліди з внесенням фосфогіпсу як хімічного меліоранту. Схема дослідів передбачала внесення фосфогіпсу у різні періоди року меліоративними нормами 1.4, 3.0 та 6.0 т/га. Відбір проб, лабораторні аналізи та опрацювання отриманих результатів виконано із застосуванням стандартизованих методів досліджень. На ділянках досліджень встановлено високий вміст солей в орному шарі ґрунту (0.35-0.48 %), ознаки осолонцювання (вміст обмінного натрію 3.64 %) та незадовільний фізичний стан ґрунту. Внесення фосфогіпсу привело до збільшення аніонів сульфату, що відображалося на сульфатному хімізмі ґрунту, а на контрольних ділянках зберігався содово-сульфатний тип засолення. Встановлено, що рівень pH водної витяжки за роки досліджень знаходився в межах нейтральних значень. Позитивні зміни спостерігали при визначенні ступеня засолення ґрунту, а саме при внесенні фосфогіпсу нормами 3 та 6 т/га на поливних ділянках ступінь засолення змінювався з середнього до слабко засоленого. За результатами зменшення натрієво-адсорбційного відношення доведено позитивну дію внесення фосфогіпсу при зрошенні на третій рік післядії. Відмічається краща меліоративна дія фосфогіпсу при поливах за рахунок зменшення показника натрієво-адсорбційного відношення щодо контрольних варіантів на 69 %. За умов поливу водою II класу якості найкращим варіантом внесення фосфогіпсу є дози 3 т/га під культивацію навесні та 6 т/га під основний обробіток восени. Це забезпечує зниження ступеня засолення ґрунтів та дозволяє покращити еколого-меліоративний стан території при зрошенні

Ключові слова: меліорація земель; зрошення; осолонцювання; фосфогіпс; натрієво-адсорбційне відношення; ступінь засолення