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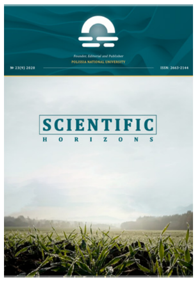

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Transformation of soil fertility under long-term irrigation with mineralised water

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Abstract. Irrigation with saline water is a challenging yet necessary practice for maintaining sustainable crop production in arid and semi-arid regions, particularly under conditions of climate change and freshwater scarcity. Given the potentially harmful effects of saline water on soil properties, particularly fertility, the primary aim of this study was to determine the extent of impact effects on dark chestnut soils in southern Ukraine, resulting from continuous irrigation of croplands with mineralised water from the Inhulets irrigation system. The Inhulets irrigation water is characterised by a high sodium content (10.49-21.63 me/L), elevated levels of toxic ions (11.83 21.97 me/L), and a high total dissolved solids content (1489-2280 mg/L). The research was conducted between 2003 and 2018 in the Bilozerka District of the Kherson Region. Soil fertility was assessed using the following indicators: humus content and nitrogen, phosphorus, and potassium concentrations. Changes in soil traits were evaluated for statistical significance at $P < 0.05$ using the Mann-Kendall trend test and cumulative sums of change methods. The findings revealed a statistically significant trend towards a decline in soil humus content (-0.73%; Z-statistic: 2.0381). Conversely, slight but statistically insignificant increasing trends were observed in nitrogen, phosphorus, and potassium concentrations (+9, +2, and +65 mg/kg, respectively; Z-statistics: 0.6794, 0, and 0, respectively). Notably, positive changes were primarily observed after 2013, whereas the earlier period was predominantly characterised by declining soil fertility across all studied indicators. The study's outcomes hold significant practical value as they highlight the long-term effects of continuous irrigation with mineralised water on soil fertility. These findings provide crucial insights into land reclamation and agrochemical measures necessary to mitigate soil degradation and ensure sustainable agricultural practices in vulnerable agroecosystems

Keywords: humus; land reclamation; nitrogen; phosphorus; potassium; salinity

INTRODUCTION

Current challenges in agriculture are predominantly associated with food security, which is increasingly under threat due to global population growth, degradation of natural resources, environmental pollution, climate change, irrational anthropogenic activities, and, notably, the intensification of military conflicts. Ensuring an adequate supply of food, both in terms of quantity and quality, to meet the growing nutritional demands has become an increasingly complex task each successive year. Irresponsible human activities and inefficient utilisation of natural resources – such as soil, water, biological organisms, and meteorological resources inputs – have not only significantly worsened global ecological conditions but also caused a severe decline in agricultural land productivity (Wolski *et al.*, 2020). Coupled with climate change and its associated impacts, including unstable weather patterns and an increased frequency of extreme meteorological events – such as prolonged droughts, hailstorms, flooding, and rapid, unpredictable changes in air temperature – this situation has undermined the sustainability of agroecosystems. Consequently, food insecurity has worsened in the most vulnerable regions, such as sub-Saharan Africa, southern Africa, and South Asia, noted by as K. Ouko and M. Odiwuor (2023). Furthermore, the COVID-19 pandemic exacerbated malnutrition in these areas, intensifying food insecurity, particularly in Asia and Africa, as observed by G. Rasul (2021). To counteract the adverse effects of climate change and meet food demands, it is imperative to develop and implement effective measures for conserving natural resources in agriculture. Soil, as it is the primary environment and fundamental resource for agricultural production, should be prioritised. Moreover, soil quality plays a critical role in enhancing climate resilience, as emphasised by L. Qiao *et al.* (2022). H. El-Ramady *et al.* (2022) highlighted the crucial role of soil fertility in ensuring human well-being. It is evident that soil preserving soil is not only vital for agroecological sustainability but also essential for socio-economic stability. The success or failure of soil preservation efforts will be pivotal in determining the survival of future generations.

Soil conservation is a multifaceted process involving various soil management practices, such as rational tillage, fertilisation, optimal crop rotations, amelioration techniques, and soil microbiota preservation methods. Among the key components of healthy soil are its ameliorative conditions and nutrient status, which are shaped by numerous biological and anthropogenic factors. One significant determinant is the quality of irrigation water, which plays a pivotal role in influencing soil properties. M. Licata *et al.* (2022) confirmed that irrigation can significantly affect soil properties, but its impact depends on the irrigation method, the quality of the water, the initial soil properties, and the soil's susceptibility to external influences. Irrigation influences soil structure, water permeability, physical and chemical properties, ameliorative conditions, and overall fertility.

Irrigation with saline water, characterised by high levels of total dissolved solids and elevated sodium content, is particularly detrimental to both plants and soils. Risks of secondary salinisation and sodification are further exacerbated by improper tillage and fertilisation practices. The accumulation of toxic salts degrades soil chemical properties and structure, impairs nutrient uptake by plants, and reduces crop yields. When sodium accumulates in the soil, the structure deteriorates further, leading to soil crusting, reduced water infiltration, diminished porosity, and inadequate aeration. V. Phogat *et al.* (2020) and B. Hailu and H. Mehari (2021) warned that these adverse processes hinder the growth and development of agricultural crops and, if not properly managed, can render soils unsuitable for agricultural use. P. Lykhovyd (2021) emphasised that southern Ukraine, located in a semi-arid climatic zone, relies heavily on irrigation for the overall crop production and sustainable development of agriculture. However, a significant portion of land in the region is irrigated with water of suboptimal quality. L. Hranovska *et al.* (2022) noted that the Inhulets irrigated land array, continuously supplied with water from the Inhulets irrigation system, is affected by high levels of total dissolved solids and sodium. In light of the potential hazards of soil degradation and fertility loss, this study aimed to investigate the long-term impacts of irrigation and agricultural activities on soil fertility indicators in the Inhulets irrigated land array.

MATERIALS AND METHODS

The study was conducted between 2003 and 2018 through in-field soil surveys on the Inhulets irrigated land array in the Bilozerka District of Kherson Region, southern Ukraine. Data collected after this period are incomplete due to disruptions caused by the COVID-19 pandemic and military activities in the region. The climate of the study area is characterised as semi-arid, with a deficient natural water balance (Lykhovyd, 2021). The soil in the region is classified as typical dark-chestnut, medium-loamy soil. The Inhulets irrigation system provides water to farms in the Kherson and Mykolaiv regions of Ukraine. To ensure the safety of plants and soil, the water quality requires substantial improvement, as it is contaminated by waste and effluent discharges from metallurgical enterprises. According to the specifications of the national standard DSTU 2730:2015 (2016), the water is classified as "Limited suitable for irrigation" (second class). Similarly, based on international standards and methodologies for agricultural water quality assessment outlined by the FAO (n.d.) and DSTU 2730:2015 (2016), the Inhulets irrigation water is deemed to have limitations for irrigation use (Pescod, 1992). High levels of sodium (10.49-21.63 me/L), toxic ions (11.83-21.97 me/L), and total dissolved solids (1489-2280 mg/L) are the primary issues associated with the Inhulets irrigation water. The use of such water for irrigation adversely affects the physical, chemical, and biological properties of the soil, leading to a decline in crop growth, productivity, and yield quality (Lykhovyd & Kozlenko, 2018). Consequently, it is crucial to assess the long-term effects of irrigation with such water on soil properties, particularly fertility indicators such as humus and macronutrient content.

Humus content in soil was determined using the Turin method (DSTU 7855:2015, 2016). Nitrogen content was assessed indirectly through the soil nitrification activity method developed by Kravkov (DSTU 7538:2014, 2015). The content of mobile phosphorus and exchangeable potassium was measured using the Machygin method (DSTU 4114-2002, 2003). The presence or absence of statistically significant trends in soil humus and macronutrient content was evaluated using the MannKendall trend test at $P < 0.05$ (Hamed, 2008). Additionally, the cumulative sums of change (CUSUM) algorithm were applied to identify trends and determine points of change in the time series of soil properties (Sabir *et al.,* 2024). All calculations were performed using a self-developed script in Python 3, with the VS Code IDE as the development environment.

RESULTS AND DISCUSSION

Humus is a dynamic and complex mixture of organic compounds formed through the decomposition and humification of plant and animal residues. It constitutes the primary component of overall soil organic matter and is a critical factor in soil fertility, formation, contributing to carbon storage and influencing soil buffer capacity, structure, and microbiota (Gerke, 2022). Irrigation significantly alters the processes of humus formation and related dynamics. The quantitative humus content exhibits zonal characteristics, determined by soil genesis factors such as soil formation type, granulometric composition, vegetation type, and agrotechnological practices (Baliuk *et al.*, 2020). This applies to the dark-chestnut irrigated soils of the Inhulets irrigated land array, as confirmed by the results of the soil survey (Table 1). The findings from the CUSUM analysis indicate a trend towards dehumification (Fig. 1). Long-term irrigation of highly mineralised water has resulted in an overall decline in humus content in the surveyed soils, averaging a reduction of 0.046% per year. The Mann-Kendall trend test confirmed a statistically significant trend of decreasing humus content, with a Z-statistic of 2.0381. Between 2003 and 2018, the weighted average humus content in the land array fell by 0.73%.

Table 1. *Weighted average indicators of humus content in irrigated soils in the Bilozerka District of Kherson Region (Inhulets irrigated land array, 2003-2018)*

Year	Humus, %	Gradation	± to previous
2003	2.43	Moderate	-
2008	2.34	Moderate	-0.09
2013	2.16	Moderate	-0.18
2018	1.70	Low	-0.46

Source: compiled by the authors

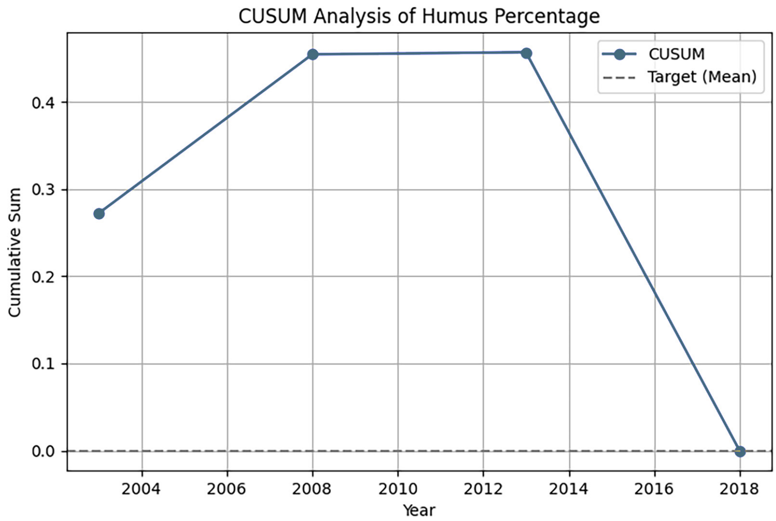

***Figure 1**. CUSUM plot for humus content in irrigated soils in the Bilozerka District of Kherson Region (Inhulets irrigated land array, 2003-2018)*
***Source:** compiled by the authors*

Continuous irrigation with highly mineralised water has led to a decline in soil areas with high or moderately high humus content, resulting in their reclassification into categories of moderate and low humus content (Table 2). The spatial variability of soil properties is primarily characterised by non-stationary (atypical) patterns in their distribution across irrigated agricultural landscapes. This variability is largely influenced by agricultural practices and soil biodiversity levels.

Table 2. *Comparative assessment of irrigated and non-irrigated lands in the Bilozerka District of Kherson Region (Inhulets irrigated land array), by humus content, %*

Land array	Area, ha	Area ordered by the humus content												Weighted average indicator, %
		Very low < 1.1%		Low 1.1-2.0%		Moderate 2.1-3.0%		Moderately high 3.1-4.0%		High 4.1-5.0%		Very high > 5.0%		
		ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	
2013 year														
Total areas	98,226.6	368.8	0.4	58,538.8	59.6	37,239.2	37.9	2,079.8	2.1	-	-	-	-	2.06
Non-irrigated arable land	83,368.5	-	-	50,559.3	51.5	31,153.5	31.7	1,655.7	1.7	-	-	-	-	2.06
Irrigated arable land	11,109.5	-	-	5,102.2	5.2* 45.9**	5,689.9	5.8 51.2	317.5	0.3 2.9	-	-	-		2.16
2018 year														
Total areas	96,853.5	3,294.2	3.4	61,220.2	63.2	27,746.7	28.6	4,430.8	4.6	12.9	0.0	148.8	0.2	1.97
Non-irrigated arable land	88,401.9	2,321.7	2.4	55,341.8	57.1	26,189.3	27.0	4,387.5	4.5	12.9	0.0	148.8	0.2	2.00
Irrigated arable land	6,206.4	592.6	0.6 9.6	4,412.6	4.6 71.01	1,190.4	1.2 19.2	10.8	0.0 0.2	-	-	-	-	1.70

***Note:** * – share of the total surveyed land; ** – share of the surveyed irrigated land*
***Source:** compiled by the authors*

The characteristics of the soil cover determine the initial humus content, which, during economic activity, undergoes dynamic changes influenced by the intensity and level of agriculture within land plots. Under conditions of continuous irrigation with highly mineralised waters from the Inhulets irrigation system, the humus content is, on average, 0.3% lower than in non-irrigated lands. This reduction results from the intensity and technological aspects of irrigated land reclamation, including poor water quality, irrigation rates, and crop rotation practices.

Dehumification of soils under continuous irrigation with saline water can be attributed to the increased mineralisation of organic matter due to intensive cultivation, imbalance in production and soil-forming processes, inadequate incorporation of crop residues and organic fertilisers into the arable layer, a rise in fallow crops, a decline in the share of perennial grasses, and the absence of field crop rotations. Prolonged unilateral application of mineral fertilisers particularly physiologically acidic forms, insufficient use of plant residues as green manure, and burning of stubble and crop residues, exacerbate this issue. These factors contribute to erosion, including irrigation-inducted soil erosion and deflation. Changes in humus content also occur due to long-term irrigation practices (Vozhehova, 2021).

Another important constituent of soil health and fertility is the content of plant-available micronutrients such as nitrogen, phosphorus, and potassium. Nitrogen plays a crucial role in enhancing crop yields. It is a component of proteins, which constitute the cytoplasm and cell nucleus, as well as amino acids, nucleic acids, chlorophyll, alkaloids, phosphatides, vitamins, enzymes, and other biologically active substances essential for normal plant growth and development (Toor *et al.,* 2021). The primary sources of nitrogen for plants include organic and mineral fertilisers, soil organic matter, biological nitrogen fixation, and nitrogen introduced through atmospheric precipitation. The nitrogen nutrition regime of plants in the soils of southern Ukraine is a critical characteristic of soil fertility, with nitrogen often being the most limiting nutrient. The ammonium nitrogen content in soils serves as an indicator of soil management practices and is an indirect measure of soil fertility. Additionally, higher soil nitrifying activity is regarded as a sign of fertile soil (Gamajunova *et al.,* 2021).

Under continuous irrigation, the dark-chestnut soils of the Inhulets irrigated land array exhibit an increase in the content of available nitrogen over time. CUSUM analysis indicates a trend towards nitrogen content increment in the examined soils following its sharp decline before 2013 (Fig. 2). However, this trend is statistically insignificant, according to the Mann-Kendall trend test, with a Zstatistic of 0.6794 (Table 3).

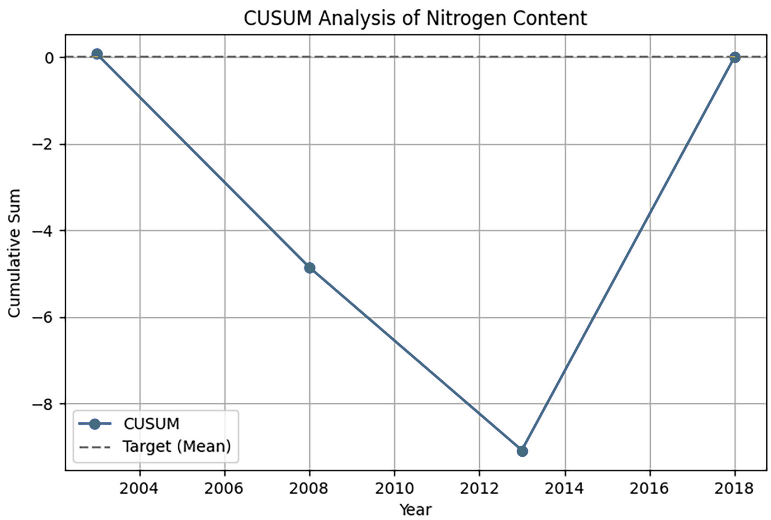

Figure 2*. CUSUM plot for nitrogen content in irrigated soils in the Bilozerka District of Kherson Region (Inhulets irrigated land array, 2003-2018)*

Source: *compiled by the authors*

Table 3*. Weighted average indicators of nitrogen content in irrigated soils in the Bilozerka District of Kherson Region (Inhulets irrigated land array, 2003-2018)*

Year	Nitrogen, mg/kg	Gradation	± to previous
2003	27.0	Moderately high	
2008	22.0	Moderately high	-5.0
2013	22.7	Moderately high	+0.7
2018	36.0	High	+13.3

Source: *compiled by the authors*

The nitrogen content in the irrigated soils, which corresponds to quality gradations ranging from moderate to high (8.1-30.0 mg/kg), accounts for 37.0% of the agricultural land area. The largest share (59.2%) consists of areas with high nitrogen content (Table 4). The weighted average nitrogen content under continuous irrigation is higher than that of non-irrigated lands.

***Table 4**. Comparative assessment of irrigated and non-irrigated lands in the Bilozerka District of Kherson Region (Inhulets irrigated land array), by nitrogen content, mg/kg*

Land array	Area, ha	Areas of soils ordered by nitrogen content												Weighted average indicator, mg/kg
		Very low		Low		Moderate		Moderately high		High		Very high		
		< 5.0		5.1-8.0		8.1-15.0		15.1-30.0		30.1-60.0		> 60.0		
		ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	
2013 year														
Total areas	98,226.6	4,195.8	4.3	11,139.6	11.3	38,021.8	38.7	29,760.0	30.3	14,324.5	14.6	785.0	0.8	18.0
Non-irrigated arable land	83,368.5	2,997.7	3.6	10,468.4	12.6	32,510.2	39.0	26,145.2	31.4	10,847.5	13.0	399.6	0.5	17.4
Irrigated arable land	11,109.5 100	110.8	1.0	396.5	3.6	4,739.0	42.7	2,549.0	22.9	2,936.7	26.4	377.5	3.4	22.7
2018 year														
Total areas	96,853.5	305.4	0.3	581.6	0.6	9,229.3	9.5	40,260.6	41.6	41,523.5	42.9	4,953.2	5.1	31.7
Non-irrigated arable land	88,401.9	86.9	0.1	24.0	0.0	8,511.7	9.6	37,552.4	42.5	37,480.5	42.4	4,746.5	5.4	31.8
Irrigated arable land	6,206.4	34.0	0.5	0.0	0.0	158.3	2.6	2,132.9	34.4	3,674.5	59.2	206.7	3.3	36.0

***Source:** compiled by the authors*

Phosphorus is one of the most important elements in plant nutrition. After organic matter and nitrogen, phosphorus is often the most deficient element in crop cultivation. It is a component of nucleoproteins, sugar phosphates, phosphatides, and other compounds, actively participating in metabolic processes of protein synthesis, determining cellular energy dynamics, and influencing plant growth (Toor *et al.*, 2021). A substantial proportion of available soil phosphorus is stored in soil organic matter. When organic matter is depleted due to intensive tillage, erosion, and unsustainable agricultural practices, phosphorus deficiency becomes a pressing issue. No statistically significant trend was observed in soil phosphorus dynamics under continuous irrigation with mineralised water; the Z-statistic from the Mann-Kendall trend test equals zero (Table 5). However, a slight upward trend was evident in the CUSUM plot after 2013 (Fig. 3).

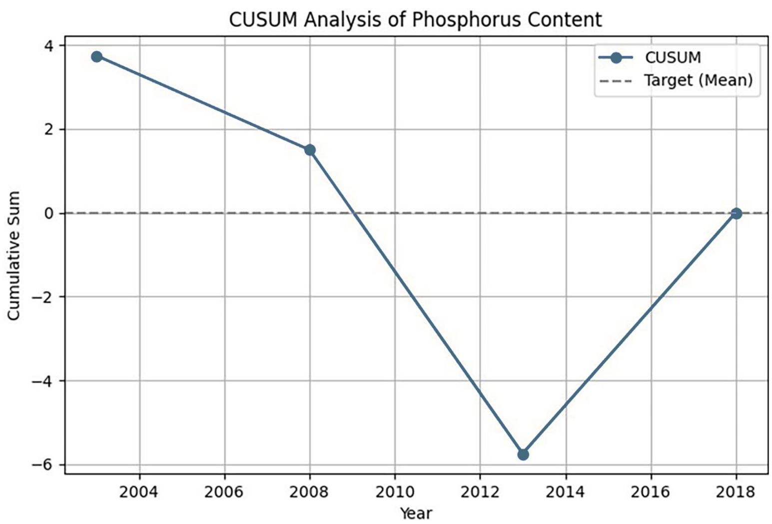

***Figure 3**. CUSUM plot for phosphorus content in irrigated soils in the Bilozerka District of Kherson Region (Inhulets irrigated land array, 2003-2018)*

***Source:** compiled by the authors*

***Table 5**. Weighted average indicators of phosphorus content in irrigated soils in the Bilozerka District of Kherson Region (Inhulets irrigated land array, 2003-2018)*

Year	Phosphorus, mg/kg	Gradation	± to previous
2003	62.0	Very high	-
2008	56.0	High	-6.0
2013	51.0	High	-5.0
2018	64.0	Very high	+13.0

***Source:** compiled by the authors*

Very high phosphorus content (> 60.0 mg/kg) characterises 40.6% of the irrigated land area. High phosphorus content (46-60 mg/kg) accounts for 15.48% of the area, while moderately high phosphorus levels (31-45 mg/kg) represent 20.89% of the surveyed area (Table 6). The weighted average content of mobile phosphorus compounds under continuous irrigation with mineralised waters of the Inhulets irrigation system is higher than in non-irrigated lands.

***Table 6**. Comparative assessment of irrigated and non-irrigated lands in the Bilozerka District of Kherson Region (Inhulets irrigated land array), by the content of mobile phosphorus compounds*

Land array	Area, ha	Areas of soils ordered by phosphorus content						Weighted average indicator, mg/kg
		Very low < 11	Low 11-15	Moderate 16-30	Moderately high 31-45	High 46-60	Very high ➢ 60	
		ha	ha	ha	ha	ha	ha	
2013 year								
Total areas	98,226.6	120.6	2,293.1	24,773.6	23,911.7	14,450.1	32,677.5	48
Non-irrigated arable land	83,368.5	63.6	1,999.6	21,664.6	20,856.0	12,256.2	26,528.5	47
Irrigated arable land	11,109.5	57.0 0.51	285.6 2.57	2,211.7 19.91	2,321.3 20.89	1,720.0 15.48	4,514.0 40.63	51
2018 year								
Total areas	96,853.5	0.0	133.1	6,172.1	11,124.8	9,336.3	70,087.2	65
Non-irrigated arable land	88,401.9	0.0	133.1	5,820.2	9,932.0	9,052.9	63,463.7	65
Irrigated arable land	6,206.4	0.0	0.0	351.9	1,153.8	283.4	4,417.3	64

***Source:** compiled by the authors*

The most effective measure for replenishing the mobile phosphorus content in irrigated soil is the application of phosphorus-containing mineral fertilisers. Phosphorus in mineral fertilisers, under certain environmental conditions, is more mobile and available to plants than that in organic fertilisers. Therefore, rational phosphorus fertilisation is critical for maintaining a positive balance of this essential nutrition in the soils irrigated with mineralised waters. In addition to the direct input of phosphorus through fertilisation, it is possible to increase the mobile forms of this element in soil by employing phosphorus-mobilising bacterial strains. These strains not only enhance soil fertility but also improve overall soil health and promote environmental sustainability (El Attar *et al.,* 2022).

Potassium plays an essential role in the life cycle of crops. It indirectly participates in nitrogen metabolism, influences the accumulation of amino acids and energy processes, and regulates respiration. The presence of various forms of potassium in soils is associated with primary and secondary minerals, as well as the characteristics of their transformations. Potassium is the most mobile element, migrating both into plants and within the soil. The total volume of potassium in the soils of southern Ukraine is typically much higher than that of nitrogen or phosphorus. The richer the soil is in clay and organic matter, the higher its total potassium content. The total potassium content, along with its mobile forms (water-soluble, exchangeable, and non-exchangeable), determines the potassium regime of the soil. The primary source of potassium available to plants is exchangeable potassium, which is stored in the soil adsorption complex (Toor *et al.,* 2021). The content of exchangeable potassium in irrigated soils is strongly influenced by natural zonal features. Different soil types are characterised by varying amounts of exchangeable potassium. More potassium is typically found in heavy clay and loamy soils, whereas sandy and sandy loamy soils are characterised by significantly lower potassium content (Breus & Skok, 2021).

Despite a notable increase in microelement content in 2018 (Table 7), the Mann-Kendall test did not identify any significant trend in the content of exchangeable potassium (Z-statistic is zero). Figure 4 illustrates a steep increase in potassium content in the investigated soils after 2013, similar to trends previously observed for nitrogen and phosphorus. This dynamic change suggests that a significant event in soil amelioration occurred in 2013.

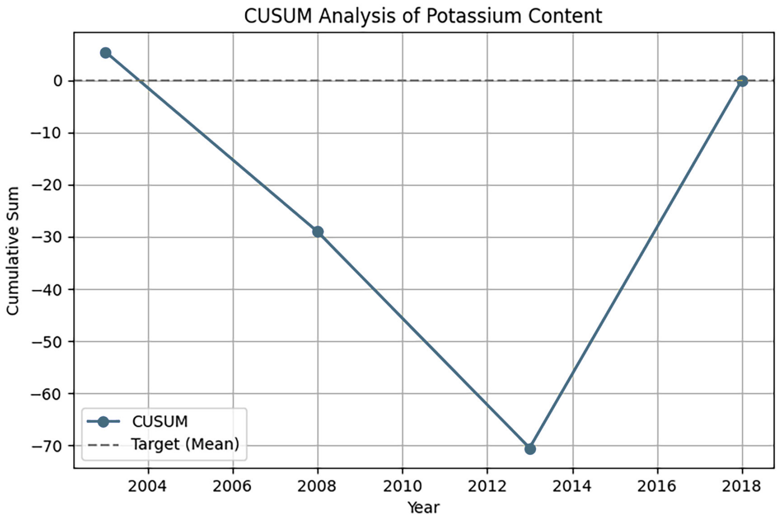

***Figure 4**. CUSUM plot for potassium content in irrigated soils in the Bilozerka District of Kherson Region (Inhulets irrigated land array, 2003-2018)*
***Source:** compiled by the authors*

***Table 7**. Weighted average indicators of content of exchangeable potassium compounds in irrigated soils in the Bilozerka District of Kherson Region (Inhulets irrigated land array, 20032018)*

Year	Potassium, mg/kg	Gradation	± to previous
2003	410	Very high	
2008	370	High	-40.0
2013	363	High	-7.0
2018	475	Very high	+112.0

***Source:** compiled by the authors*

The content of exchangeable potassium in soils (Table 8), categorised by gradations, shows that very high content potassium levels (>400.0 mg/kg) characterise 68.1% of the irrigated land area. High potassium content (301-400 mg/kg) accounts for 23.05% of the area, while moderately high levels (201-300 mg/kg) – represent 8.93% of the surveyed area. Overall, irrigation with Inhulets water did not significantly affect the content of exchangeable potassium in the examined soils.

***Table 8**. Comparative assessment of irrigated and non-irrigated lands in the Bilozerka District of Kherson Region (Inhulets irrigated land array), by the content of exchangeable potassium*

Land array	Area, ha	Areas of soils ordered by potassium content						Weighted average indicator, mg/kg
		Very low < 51	Low 51-100	Moderate 101-200	Moderately high 201-300	High 301-400	Very high > 400	
		ha	ha	ha	ha	ha	ha	
2013 year								
Total areas	98,226.6	0.0	0.0	8,686.8	30,052.9	31,231.2	28,255.8	364
Non-irrigated arable land	83,368.5	0.0	0.0	7,321.9	25,545.5	26,240.3	24,260.7	365
Irrigated arable land	11,109.5	0.0	0.0	406.0	3,593.0	4,130.8	2,979.8	363
2018 year								
Total areas	96,853.5	0.0	6.2	60.3	10,004.3	15,240.8	71,541.9	502
Non-irrigated arable land	88,401.9	0.0	6.2	60.3	9,410.9	13,810.0	65,114.5	503
Irrigated arable land	6,206.4 100	0.0 0.0	0.0 0.0	0.0 0.0	554.4 8.93	1,430.8 23.05	4,221.2 68.01	475

***Source:** compiled by the authors*

As a result, it should be stated that the Inhulets irrigation water had a significant effect on the dark-chestnut soils of the Belozerka District in terms of humus content (a negative tendency towards a decrease) and available nitrogen content (a positive trend towards an increase). No statistically significant trend was observed in mobile phosphorus or exchangeable potassium. Therefore, it can be concluded that mineralised water has a strong adverse effect on soil organic matter accumulation but has little to no significant impact on the availability of mineral macronutrients in soils. However, as general soil salinity increases – particularly when combined with sodium accumulation – the availability of macronutrients from the soil decreases, as plants struggle to absorb nutrients under conditions of high osmotic pressure in the soil solution, and unfavourable soil structure.

A. Mohanavelu *et al.* (2021) claim that approximately one-third of the total irrigated land areas globally are subject to the negative impacts of secondary salinisation and sodification. These issues arise as a consequence of irrigation and, in turn, result in the inhibition of agricultural plant growth and development, as well as a reduction in effective soil fertility and the overall sustainability of agricultural ecosystems. The authors suggest that soil salinity and sodicity pose a significant threat to food security and require the development of effective mitigation strategies, particularly for irrigated lands. Among the possible solutions, A. Mohanavelu *et al.* (2021) recommend improved drainage systems, monitoring of irrigation water usage and quality, and the cultivation of salt-tolerant crops with phytoremediation properties.

In a short-term study, A. Turdaliev *et al.* (2022) also observed no significant effects of irrigation with mineralised water on winter wheat yields or soils. However, they acknowledged that the study spanned only a three-year period and noted some degree of sodium accumulation, which is potentially hazardous due to the risk of secondary soil sodification and the deterioration of its physical and chemical properties. Comprehensive studies confirm the harmful effects of saline water irrigation on plants and soils, resulting in drastic reductions in crop yields and deterioration in soil quality (Cheng *et al.,* 2021). Soil salinity has been shown to increase significantly, even under shortterm irrigation with water salinity exceeding 4.0 dS/m, and water salinity levels higher than 4.4 dS/m are deemed unsuitable for irrigation. When no alternative water sources are available, mineralised irrigation water must be used cautiously and accompanied by careful soil monitoring to prevent soil salinisation and sodification (Feng *et al.,* 2021). Amelioration measures, such as gypsum application, rational tillage, and crop rotation systems – particularly those which involve crops with phytoremediation capacities such as alfalfa, chickpea, and melilot – along with irrigation water pretreatment, are crucial for preserving soil health under conditions of saline water irrigation (Kankarla *et al.,* 2020).

According to K. Negacz *et al.* (2022), approximately 17 million km^2 of global soil cover is subject to the negative effects of salinity, and only 11.76% of these soils show potential for agricultural use. The greatest future potential for saline agriculture is associated with salt-affected soils in non-depleted basins, with or without irrigation, while the least promising soils are found in depleted basins. Saline water irrigation can exacerbate problems associated with salt-affected soils, reducing water and nutrient availability for agricultural plants and decreasing soil fertility. The metaanalysis conducted by M. Cheng *et al.* (2021) revealed that saline water irrigation leads to crop yield losses and reduced water use efficiency, in addition to posing various hazards to soil health. The most salt-tolerant crops identified were cotton, wheat, and grain maize. As a measure to mitigate the adverse impacts of mineralised water on plants and soil, M. Cheng *et al.* (2021) propose the use of drip irrigation. Furthermore, it is worth noting that certain legumes exhibit significant salt tolerance and some desalination potential. Under conditions where the soil is treated with specific root-zone bacteria, such as growth-promoting rhizobacteria, beneficial effects on soils irrigated with mineralised water have been observed, without significant reduction in yield (Hussain *et al.,* 2020; Hafez *et al.,* 2021).

Although saline water irrigation poses environmental hazards and contributes to crop losses, some scientists argue that under conditions of water scarcity – prevalent in global agriculture over recent decades – irrigation with pre-treated mineralised water could provide a viable solution for ensuring food security. However, this approach would necessitate careful ecological monitoring and crop system diversification within the framework of resource-efficient climate-smart agriculture on marginal croplands.

CONCLUSIONS

As a result of a long-term investigation, it was determined that continuous irrigation with mineralised water results in a significant decrease in soil humus content. From 2003 to 2018, humus content in the investigated dark-chestnut soils decreased from 2.43% to 1.70%, equating to 42.94%. Regarding macronutrients, no general adverse effects were identified. However, for induvial nutritious, nitrogen content increased by 9.0 mg/kg (33.33%); phosphorus content increased by 2.0 mg/kg (3.23%); and potassium content increased by 65 mg/kg (15.85%). Nevertheless, the general deterioration of soil structure, along with sodium accumulation and increased osmotic pressure in the soil solution, may reduce the efficiency of nutrient uptake by agricultural plants. Irrigation with saline water should only be conducted if no alternative options are available and must be accompanied by thorough monitoring of soil health and the implementation of precautionary amelioration measures. These measures should include gypsum application, rational tillage practices, and crop rotation systems. Further studies are required to identify and monitor the long-term effects of continuous irrigation with mineralised water from the Inhulets irrigation system on the soils of the irrigated land array. This research should encompass not only dark-chestnut soils but also other soil types, present in the specified land array. Additionally, beyond fertility parameters, factors such as biological activity, soil microbiota composition, and the physical, chemical, and mechanical properties of soils must be assessed to provide the most comprehensive evaluation of land conditions and their dynamic changes resulting from irrigation.

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CONFLICT OF INTEREST

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REFERENCES

[1] Baliuk, S., Zakharova, M., Vorotyntseva, L., Leah, T., & Filipciuc, V. (2020). Changes in the humus state of chernozems of Ukraine and Moldova under irrigation. *Scientific Papers. Series A. Agronomy*, Vol. LXIII(2), 11-17.
[2] Breus, D., & Skok, S. (2021). Spatial modelling of agro-ecological condition of soils in steppe zone of Ukraine. *Indian Journal of Ecology*, 48(3), 627-633.
[3] Cheng, M., Wang, H., Fan, J., Wang, X., Sun, X., Yang, L., Zhang, S., Xiang, Y., & Zhang, F. (2021). Crop yield and water productivity under salty water irrigation: A global meta-analysis. *Agricultural Water Management*, 256, article number 107105. doi: 10.1016/j.agwat.2021.107105.
[4] DSTU 2730:2015. (2016). *Environmental protection quality of natural irrigation water. Agronomical criteria*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=62381.
[5] DSTU 4114-2002. (2003). *Soils. Determination of mobile phosphorus and potassium compounds by the modified Machigin method*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=58928.
[6] DSTU 7538:2014. (2015). *Soil quality. Determination of soil nitrification capacity by the Kravkov method*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=64090.
[7] El Attar, I., Hnini, M., Taha, K., & Aurag, J. (2022). Phosphorus availability and its sustainable use. *Journal of Soil Science and Plant Nutrition*, 22, 5036-5048. doi: 10.1007/s42729-022-00980-z.
[8] El-Ramady, H., Brevik, E.C., Elsakhawy, T., Omara, A.E.D., Amer, M.M., Abowaly, M., El-Henawi, A.S., & Prokisch, J. (2022). Soil and humans: A comparative and a pictorial mini-review. *Egyptian Journal of Soil Science*, 62(2), 101-122. doi: 10.21608/EJSS.2022.144794.1508.
[9] FAO. (n.d.). Retrieved from https://www.fao.org/home/en.
[10] Feng, G., Zhu, C., Wu, Q., Wang, C., Zhang, Z., Mwiya, R.M., & Zhang, L. (2021). Evaluating the impacts of saline water irrigation on soil water-salt and summer maize yield in subsurface drainage condition using coupled HYDRUS and EPIC model. *Agricultural Water Management*, 258, article number 107175. doi: 10.1016/j.agwat.2021.107175.
[11] Gamajunova, V., Panfilova, A., Kovalenko, O., Khonenko, L., Baklanova, T., & Sydiakina, O. (2021). Better management of soil fertility in the southern steppe zone of Ukraine. In *Soils under stress: More work for soil science in Ukraine* (pp. 163-171). Cham: Springer International Publishing. doi: 10.1007/978-3-030-68394-8_16.
[12] Gerke, J. (2022). The central role of soil organic matter in soil fertility and carbon storage. *Soil Systems*, 6(2), article number 33. doi: 10.3390/soilsystems6020033.
[13] Hafez, E.M., Osman, H.S., El-Razek, U.A.A., Elbagory, M., Omara, A.E.D., Eid, M.A., & Gowayed, S.M. (2021). Foliar-applied potassium silicate coupled with plant growth-promoting rhizobacteria improves growth, physiology, nutrient uptake and productivity of faba bean (*Vicia faba* L.) irrigated with saline water in salt-affected soil. *Plants*, 10(5), article number 894. doi: 10.3390/plants10050894.
[14] Hailu, B., & Mehari, H. (2021). Impacts of soil salinity/sodicity on soil-water relations and plant growth in dry land areas: A review. *Journal of Natural Sciences Research*, 12(3), 1-10. doi: 10.7176/JNSR/12-3-01.
[15] Hamed, K.H. (2008). Trend detection in hydrologic data: The Mann-Kendall trend test under the scaling hypothesis. *Journal of Hydrology*, 349(3-4), 350-363. doi: 10.1016/j.jhydrol.2007.11.009.
[16] Hranovska, L., Morozov, O., Pisarenko, P., & Vozhegov, S. (2022). Ecological problems of irrigated soils in the south of Ukraine. *Visnyk of VN Karazin Kharkiv National University, Series "Geology. Geography. Ecology"*, 57, 282-295. doi: 10.26565/2410-7360-2022-57-21.
[17] Hussain, M.I., Farooq, M., Muscolo, A., & Rehman, A. (2020). Crop diversification and saline water irrigation as potential strategies to save freshwater resources and reclamation of marginal soils – A review. *Environmental Science and Pollution Research*, 27(23), 28695-28729. doi: 10.1007/s11356-020-09111-6.

[18] Kankarla, V., Shukla, M.K., Picchioni, G.A., VanLeeuwen, D., & Schutte, B.J. (2020). Germination and emergence responses of alfalfa, triticale and quinoa irrigated with Brackish groundwater and desalination concentrate. *Agronomy*, 10(4), article number 549. doi: 10.3390/agronomy10040549.
[19] Licata, M., Farruggia, D., Iacuzzi, N., Leto, C., Tuttolomondo, T., & Di Miceli, G. (2022). Effect of irrigation with treated wastewater on bermudagrass (*Cynodon dactylon* (L.) Pers.) production and soil characteristics and estimation of plant nutritional input. *Plos One*, 17(7), article number e0271481. doi: 10.1371/journal.pone.0271481.
[20] Lykhovyd, P. (2021). Irrigation needs in Ukraine according to current aridity level. *Journal of Ecological Engineering*, 22(8), 11-18. doi: 10.12911/22998993/140478.
[21] Lykhovyd, P.V., & Kozlenko, Y.V. (2018). Assessment and forecast of water quality in the River Ingulets irrigation system. *Ukrainian Journal of Ecology*, 8(1), 350-355. doi: 10.15421/2018_221.
[22] Mohanavelu, A., Naganna, S.R., & Al-Ansari, N. (2021). Irrigation induced salinity and sodicity hazards on soil and groundwater: An overview of its causes, impacts and mitigation strategies. *Agriculture*, 11(10), article number 983. doi: 10.3390/agriculture11100983.
[23] Negacz, K., Malek, Ž., de Vos, A., & Vellinga, P. (2022). Saline soils worldwide: Identifying the most promising areas for saline agriculture. *Journal of Arid Environments*, 203, article number 104775. doi: 10.1016/j.jaridenv.2022.104775.
[24] Ouko, K.O., & Odiwuor, M.O. (2023). Contributing factors to the looming food crisis in sub-Saharan Africa: Opportunities for policy insight. *Cogent Social Sciences*, 9(1), article number 2173716. doi: 10.1080/23311886.2023.2173716.
[25] Pescod, M.B. (1992). *Wastewater treatment and use in agriculture*. Rome: Food and Agriculture Organization of the United Nations.
[26] Phogat, V., Mallants, D., Cox, J.W., Šimůnek, J., Oliver, D.P., Pitt, T., & Petrie, P.R. (2020). Impact of long-term recycled water irrigation on crop yield and soil chemical properties. *Agricultural Water Management*, 237, article number 106167. doi: 10.1016/j.agwat.2020.106167.
[27] Qiao, L., Wang, X., Smith, P., Fan, J., Lu, Y., Emmett, B., Li, R., Dorling, S., Chen, H., Liu, S., Benton, T.G., Wang, Y., Ma, Y., Jiang R., Zhang, F., Piao, S., Muller, C., Yang, H., Hao, Y., Li, W., & Fan, M. (2022). Soil quality both increases crop production and improves resilience to climate change. *Nature Climate Change*, 12, 574-580. doi: 10.1038/s41558-022-01376-8.
[28] Rasul, G. (2021). Twin challenges of COVID-19 pandemic and climate change for agriculture and food security in South Asia. *Environmental Challenges*, 2, article number 100027. doi: 10.1016/j.envc.2021.100027.
[29] Sabir, A., Khati, U., Lavalle, M., & Srivastava, H. S. (2024). Adapting CuSUM algorithm for site-specific forest conditions to detect tropical deforestation. *Remote Sensing*, 16(20), article number 3871. doi: 10.3390/rs16203871.
[30] Toor, M.D., Adnan, M., Rehman, F.U., Tahir, R., Saeed, M.S., Khan, A.U., & Pareek, V. (2021). Nutrients and their importance in agriculture crop production: A review. *Indian Journal of Pure & Applied Biosciences*, 9(1), 1-6. doi: 10.18782/2582-2845.8527.
[31] Turdaliev, A.T., Darmonov, D.Y., Teshaboyev, N.I., Saminov, A.A., & Abdurakhmonova, M.A. (2022). Influence of irrigation with salty water on the composition of absorbed bases of hydromorphic structure of soil. *IOP Conference Series: Earth and Environmental Science*, 1068, article number 012047. doi: 10.1088/1755-1315/1068/1/012047.
[32] Vozhehova, R.A. (2021). Agroecological aspects of optimization of the system of irrigated agriculture in the Steppe zone of Ukraine under the regional climate change. In *Achievements of Ukraine and the EU in ecology, biology, chemistry, geography and agricultural sciences* (pp. 108-130). Giga: Publishing House "Baltija Publishing". doi: 10.30525/978-9934-26-086-5-6.
[33] Wolski, P., Lobell, D., Stone, D., Pinto, I., Crespo, O., & Johnston, P. (2020). On the role of anthropogenic climate change in the emerging food crisis in southern Africa in the 2019-2020 growing season. *Global Change Biology*, 26(5), article number 2729. doi: 10.1111/gcb.15047.

Трансформація родючості ґрунтів під впливом тривалого зрошення мінералізованою водою

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Анотація. Зрошення водами з високим вмістом солей є небезпечною необхідністю для сталого виробництва сільськогосподарських культур у посушливих та напівпосушливих регіонах в умовах зміни клімату та дефіциту прісної води. Враховуючи потенційний шкідливий вплив мінералізованих вод на стан ґрунтів, особливо на їх родючість, основною метою цього дослідження було встановити масштаби негативного впливу на темно-каштанові ґрунти Півдня України, який проявився внаслідок тривалого зрошення орних земель мінералізованою водою з Інгулецької зрошувальної системи. Інгулецька зрошувальна вода характеризується високим вмістом натрію (10,49-21,63 мг-екв./л), великою кількістю токсичних іонів (11,83-21,97 мг-екв./л) та високим загальним вмістом розчинних солей (1489-2280 мг/л). Дослідження проводили впродовж 2003-2018 років у Білозерському районі Херсонської області. Родючість ґрунту оцінювали за такими показниками: вміст гумусу, азоту, фосфору та калію. Достовірність змін ґрунтових ознак визначали при $P < 0,05$ за допомогою тренд-тесту Манна-Кендалла та методу кумулятивних сум змін. В результаті було встановлено, що існує статистично значуща тенденція до зменшення вмісту гумусу в ґрунті (–0,73 %; Z-статистика 2,0381); в той же час, для азоту, фосфору та калію спостерігаються незначні, але достовірні тенденції до збільшення (+9, +2, +65 мг/кг відповідно; Z-статистика 0,6794, 0, і 0 відповідно). Варто зазначити, що основна позитивна динаміка припадає на період після 2013 року, оскільки попередній період характеризується переважно зниженням родючості ґрунтів за всіма досліджуваними показниками. Результати дослідження мають високу практичну цінність і важливість, оскільки окреслюють наслідки довготривалої трансформації родючості ґрунтів під впливом безперервного зрошення мінералізованою водою, надають цінну інформацію щодо меліоративних та агрохімічних заходів, які слід враховувати в таких умовах сільськогосподарського землекористування для запобігання деградації ґрунтів у вразливих агроекосистемах

Ключові слова: гумус; меліорація ґрунту; азот; фосфор; калій; засолення