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METHODS FOR THE ELIMINATION OF SOIL SALINIZATION AND THE RECLAMATION OF UNPRODUCTIVE LANDS FOR AGRICULTURAL USE

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Abstract*:This article examines the current condition of widely distributed saline and sodic soils in Azerbaijan, their suitability for agricultural use, and possible methods for their improvement. The main objective of the study is to investigate the physicochemical properties of these soils, assess the level of salinization, and identify more effective reclamation methods for restoring soil fertility.The results of laboratory and field investigations have shown that the intensity of salinization is closely related to both natural factors and anthropogenic influences, which leads to a significant decline in soil productivity. The application of different leaching rates and reclamation measures has resulted in a noticeable reduction in soil salt content. In particular, chemical amelioration especially gypsum application combined with leaching has demonstrated higher efficiency, contributing to a substantial decrease in harmful salts and an improvement in soil structure.The findings indicate that the rehabilitation of saline soils is most effective when a comprehensive approach is applied. This includes proper irrigation management, agrotechnical practices, and the combined use of chemical amelioration methods. Such an integrated approach not only ensures the efficient use of soil resources but also supports sustainable agricultural development.The primary objective of this study is to investigate the characteristics of saline and sodic soils widely distributed across the territory of Azerbaijan, to assess their meliorative condition, and to identify more effective improvement methods for restoring soil fertility particularly evaluating the effectiveness of chemical amelioration (gypsum application).*
Keywords*:saline soil, saline-alkaline soils, soil salinization, land reclamation, melioration, irigation management, soil degradation, sustainable agriculture, GIS analysis.*

INTRODUCTION

Among soil resources, saline-alkaline soils occupy a distinctive position in terms of both their spatial distribution and inherent characteristics. Within the wide variety of soil types found worldwide, this category attracts [1-5] particular attention due to its extensive occurrence and complex formation mechanisms. In Azerbaijan, such soils are predominantly observed in the southeastern Shirvan region.These soils are typically distributed in fragmented patches among other agriculturally productive lands. This fragmented pattern complicates the timely and efficient implementation of agrotechnical measures, ultimately exerting a negative impact on overall crop productivity [6-8]. Although the soils of the Kura-Araz lowland are characterized by favorable climatic conditions, flat topography, and potential fertility, the accumulation of salts in deeper layers and the high mineralization of groundwater represent major constraints to agricultural development. This issue is particularly pronounced in irrigated areas.Since saline-alkaline soils are often distributed as localized patches, various approaches are employed for their reclamation. In modern practice, three main strategies are commonly distinguished: chemical (application of ameliorants), agrotechnical (optimization of soil management practices), and biological (cultivation of salt-tolerant crops).To ensure the effectiveness of these measures, it is essential to first examine the physical-geographical properties, geological structure, and hydrogeological conditions of the soils. At the same time, the causes and development mechanisms of salinization must be thoroughly analyzed.Research indicates that soil salinization is influenced not only by natural factors but also significantly by human activities [9-11]. In particular, improper irrigation management, delayed implementation of reclamation measures, and inefficient land use practices accelerate this process. As a result, the restoration of such soils becomes a long-term and economically challenging task.In this context, the development of environmentally grounded, integrated approaches to prevent salinization and rehabilitate affected soils is of critical importance [12-14].Such approaches aim not only to enhance productivity but also to preserve the ecological balance of the soil.The relevance of this topic is directly associated with its widespread occurrence and its detrimental impact on agriculture. In particular, in the lowland regions of Azerbaijan, this problem leads to the degradation of the soil fund and the loss of arable land [15].

EXPERIMENTAL PART

Devices:The physicochemical properties of soil samples were determined under laboratory conditions using modern instruments and standard analytical methods. Soil pH was measured with a pH meter (Hanna Instruments HI2211), while electrical conductivity was determined using the conductometric method with conductometers (Mettler Toledo SevenCompact and HANNA HI993310).The concentrations of major ions in the soil solution (Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, etc.) were determined using classical chemical analysis techniques, including titrimetric methods. The obtained results were used to assess the degree of soil salinity and sodicity.

Preparation of solutions:All solutions used in the study were prepared using analytically pure reagents and distilled water.To determine the degree of soil salinity, soil–water extracts were prepared at different ratios. For this purpose, soil and water were mixed at ratios of 1:5, 1:10, and 1:30. The mixtures were mechanically shaken for 20–30 minutes and subsequently filtered for analysis.A 0.1 N silver nitrate ($AgNO_3$) solution was prepared for the determination of chloride ions, while a 0.05 N ethylenediaminetetraacetic acid (EDTA) solution was used for the determination of calcium and magnesium ions. Buffer solutions with pH values of 4.00, 7.00, and 9.00 were used for the calibration of the pH meter.In the leaching experiments, the volumes of water were pre-calculated and adjusted to application rates of 7.5, 15, and 30 thousand m^3/ha. In the chemical reclamation treatment, gypsum ($CaSO_4 \cdot 2H_2O$) was applied at a rate of 10 t/ha and thoroughly mixed with the soil to ensure homogeneity.

All prepared solutions were maintained at constant concentrations throughout the experimental period, and laboratory conditions were carefully controlled to minimize the influence of temperature on the analytical results.The conducted research was aimed at studying the general characteristics of saline and saline-alkaline soils distributed across the territory of the Republic of Azerbaijan. Laboratory analysis of soil samples collected from various regions demonstrated that the degree of salinity is closely related to the climatic conditions of the area, the level of groundwater, and the state of irrigation systems.

RESULTS AND DISCUSSION

Based on the analytical results, it was determined that the primary issue in saline-alkaline soils is the accumulation of high concentrations of sodium ions (Na^+), which leads to the degradation of soil structure. At the same time, elevated concentrations of chloride and sulfate ions disrupt the agroecological balance of the soil and limit plant growth.The leaching experiments indicated that the removal of salts from the soil profile through irrigation is effective to a certain extent; however, when applied alone, it does not produce fully satisfactory results. Although increasing the leaching rate led to a reduction in the total salt content, the complete removal of harmful sodium salts was not achieved.

Comparative analysis indicates that chemical reclamation, particularly the application of gypsum ($CaSO_4 \cdot 2H_2O$), results in more effective soil improvement. Under the influence of gypsum, sodium ions are replaced by calcium ions, reducing the dispersion of soil colloids and enhancing structural stability.At the same time, the results demonstrate that the process of soil salinization is intensified not only by natural factors but also by anthropogenic influences. Improper management of irrigation water, inadequate drainage systems, and the delayed implementation of reclamation measures contribute significantly to the acceleration of this process [11,12,13].Overall, the findings suggest that an integrated approach is more effective in the restoration of saline-alkaline soils. The combined application of optimized irrigation regimes, chemical reclamation, and agrotechnical measures not only reduces soil salinity levels but also restores soil productivity.

Table1

Changes in the Degree of Soil Salinity (%) in Soil Samples After Leaching Using the Modeling Method

Leaching Rate m^3/ha	Leached Salts						Total Salts	Dry Residue
	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+		
Before Leaching								
	0,016	0,987	1,285	0,123	0,031	1,053	3,50	3,53
With water								
7,5	0,024	0,091	0,551	0,073	0,018	0,214	0,97	0,99
7,5	0,024	0,091	0,551	0,073	0,018	0,214	0,97	0,99
15,0	0,024	0,075	0,420	0,069	0,017	0,149	0,76	0,76

Based on the results of chemical analyses conducted after the leaching procedure, the composition of residual salts in the soil samples and their hypothetical amounts were calculated.

After applying a leaching water norm of 15 m^3/ha, the total salt content in the soil decreased to 0.75 g/100 g of soil. When the irrigation norm was increased to 30 m^3/ha, this indicator further decreased to 0.52 g/100 g of soil. These results indicate that the remaining total salts in the soil after leaching accounted for 64.4% and 70.8%, respectively.Based on the results of both leaching variants, a reduction in the content of major harmful salts in the soil was also observed. Specifically, the amounts of NaCl were determined to be 0.125 and 0.066 g, Na_2SO_4 0.308 and 0.256 g, and $MgSO_4$ 0.082 and 0.047 g, respectively (table 2).

Table 2

Percentage of Hypothetical Salts Remaining in Soil After Leaching Using the Modeling Method

Leaching Rate m³/ha	$Ca(HCO_3)_2$	$CaSO_4$	$MgSO_4$	Na_2SO_4	NaCl	Total Salts	Including Total Harmful Salts (%)
Before Leaching*							
	0,420	0,157	1,277	1,627	3,56	3,06	87,4
With water							
7,5	0,032	0,222	0,088	0,478	0,150	0,72	73.8
15,0	0,032	0,206	0,082	0,308	0,125	0,52	64,4
30,0	0,032	0,120	0,047	0,256	0,066	0,37	70,8

In the next stage of the study, leaching experiments were conducted in specially designed laboratory vessels. For this purpose, cylindrical columns with a height of 30 cm and a diameter of 5 cm were used [14,15].The experiments were carried out under two different conditions: first, leaching with plain water, and second, leaching combined with the application of gypsum ($CaSO_4 \cdot 2H_2O$) at a rate of 10 t/ha. In both cases, the leaching norm was maintained at 15 m³/ha.

Table 3

Results of the Experimental Leaching Study (%). (Reclamation Rate: 10 t/ha)

Leaching Rate m³/ha	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	Total Salts	Dry Residue
Before Leaching								
	0,022	0,689	0,796	0,061	0,029	0,710	2,31	2,32
With water								
15	0,022	0,048	0,496	0,025	0,022	0,206	0,82	0,83
Leaching with Gypsum Application								
15	0,024	0,048	0,435	0,050	0,022	0,148	0,73	0,74

In the leaching variant where 10 t/ha of gypsum was applied together with a water norm of 15,000 m³/ha, the total soil salinity level (based on dry residue) decreased from

Table 4

Percentage of Hypothetical Salts Remaining in Soil After Leaching (Gypsum Application: 10 t/ha, Leaching Rate: 15 mm m³/ha)

	$Ca(HCO_3)_2$	$CaSO_4$	$MgSO_4$	Na_2SO_4	NaCl	Total Salts	Including Total Harmful Salts (%)
Before Leaching							
0,029	0,184	0,143	0,816	1,135	2,307	2,094	90,76
With water							
0,029	0,059	0,111	0,541	0,078	0,818	0,730	80,24
Leaching with Gypsum Application							
0,032	0,144	0,112	0,361	0,078	0,727	0,551	75,73

2.32% to 0.74%.As a result of this reclamation measure, a noticeable reduction in the concentration of major ions remaining in the soil was also observed. Specifically, the concentrations of Cl^- and SO_4^{2-} ions decreased to 0.048% and 0.435%, respectively, while the amounts of Ca^{2+}, Mg^{2+}, an+d Na^+ cations were reduced to 0.050%, 0.022%, and 0.148%, respectively.

CONCLUSION

The conducted studies have established that the reclamation of saline and sodic soils for agricultural use requires prior improvement through appropriate meliorative measures. Research findings indicate that while leaching with ordinary water results in a certain reduction of soil salinity, this method does not demonstrate sufficiently high efficiency.It has been determined that increasing the leaching rate contributes to a decrease in the total salt content in the soil; however, a portion of harmful salts still remains. In contrast, chemical amelioration methods particularly leaching combined with gypsum application have proven to be more effective. Specifically, the application of gypsum significantly reduces the overall salt content in the soil, while also markedly decreasing the concentration of harmful sodium salts.At the same time, it was found that leaching with gypsum reduced the degree of soil salinity from approximately 2.3% to 0.74% per 100 grams of soil, while the level of sodicity decreased from 14.5% to 7.2%. These indicators clearly demonstrate that chemical amelioration is more effective than conventional leaching methods.Thus, based on the research results, it can be concluded that the application of an integrated approach particularly the use of chemical amelioration techniques such as gypsum treatment is more appropriate for improving saline soils and plays a significant role in restoring soil fertility.

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