

STUDY OF THE EFFECTIVENESS OF CHEMICAL REMEDICATION MEASURES IN DIFFERENT REGIONS OF THE REPUBLIC OF AZERBAIJAN

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Abstract

The article is devoted to the study of the results of leaching amelioration measures using acid solutions on saline and solonetzic soils in the irrigated areas of two major regions of the Republic of Azerbaijan - the Caspian coastal zone and the Karabakh plain. During the scientific research conducted, the characteristics of the soil cover in the studied regions were thoroughly investigated and their current improvement status was comprehensively assessed. Soil samples were collected in the study areas before and after the leaching process and subjected to chemical analysis to evaluate the effectiveness of leaching-based improvement measures. The effect of acid solutions on the properties of the leached soils was also investigated. The results of the research showed that in areas where acid leaching was used, the ameliorative efficacy was significantly higher compared to conventional water-based leaching methods, while the time required for effective leaching was 2 to 3 times shorter, depending on the dose of chemical ameliorant used. Solonetzicity was completely eliminated in all variants of acid leaching. The findings derived from the conducted research leads to the following conclusions: The soils in both regions under investigation exhibit a heavy texture and are highly saline, with moderate levels of sodicity; Chemical amelioration methods should be applied for the improvement of soils in both the Caspian coastal zone and the Karabakh region; During soil amelioration practices, the use of weak acid solutions combined with gypsum as part of the chemical amelioration process is considered optimal; It is recommended that the dosage of chemical ameliorants used in the treatment of regional soils range between 10-15 tons per hectare, with the optimal leaching rate being 15,000 m³/ha.

Keywords: amelioration; salinization; solonetzicity; acid solution; granulometric composition; leaching

I. Introduction

In recent years, the comprehensive and rapid development across the Republic has become increasingly apparent. The liberation of previously occupied territories, alongside the establishment of new residential settlements and the revitalization of industrial and agricultural sectors in these regions, signifies substantial national progress. This advancement, coupled with a steady increase in population, has brought the issue of food security to the forefront of national priorities. Addressing this challenge necessitates the improvement of soil fertility in irrigated lands and the enhancement of agricultural crop yields. Consequently, the development and implementation of more efficient and cost-effective technologies and agronomic approaches have become imperative. The present scientific investigation is devoted to addressing this pressing concern. [1-4].

The conducted scientific research has also been dedicated to addressing this issue

II. The objective of the research

It involves the development of scientifically substantiated amelioration technologies for the ecological restoration of saline and variously solonetzic soils, and their implementation in agricultural practice.

III. The research object

The research object is saline and solonetzic soils distributed across the territory of the Republic.

IV. The primary research task

The principal objective of the research is the development of scientifically grounded ameliorative agents aimed at reducing soil salinity and sodicity to agronomically acceptable thresholds, as well as ensuring their effective integration into agricultural management practices.

V. Research methodology

The scientific investigations were conducted in accordance with standardized methodological frameworks that are currently recognized and widely implemented in land reclamation and soil amelioration practices throughout the Republic.[5]

In the northeastern region of the Republic, an experimental site located within the Caspian coastal zone, covering an area of 20 hectares, was utilized to conduct the study under the following treatment variants.[6]

1. Leaching with ordinary water (control) – 8 ha;
2. Leaching with gypsum application – 8 ha
3. Leaching with 2% dilute sulfuric acid solution – 2 ha
4. Leaching with combined application of gypsum and 2% dilute sulfuric acid solution – 2 ha

Another experimental site, located in the Karabakh plain in the northwestern part of the Republic, encompassed an area of 34.5 hectares and was studied under the following treatment variants. [7]

1. Leaching with ordinary water (control) – 16 ha
2. Leaching with application of 5 tons of gypsum per hectare – 5 ha
3. Leaching with application of 10 tons of gypsum per hectare – 1 ha
4. Leaching with application of 15 tons of gypsum per hectare – 5 ha
5. Leaching with application of 5 tons of gypsum and 10 tons of 1% dilute sulfuric acid solution per hectare – 4.5 ha
6. Leaching with application of 5 tons of gypsum and 10 tons of 0.5% hydrochloric acid (HCl) solution per hectare – 3 ha

The leaching rate was standardized at 15,000 m³/ha across all treatment variants. To evaluate the efficiency of the leaching process, soil samples were systematically collected from the experimental site both before and after the treatment, and subjected to relevant chemical analyses.[8;9].

The chemical and mineralogical compositions of the raw materials and substances used in the study were determined using “58 Tiger” and “Muniflex 600” analytical instruments at the Central Laboratory for Shared Instrumentation of the Institute of Geology and Geophysics of the Azerbaijan

National Academy of Sciences (ANAS).

The radioactivity of the raw material was measured at the Institute of Radiation Problems of the Azerbaijan National Academy of Sciences (ANAS), using a Canberra "HP Ge" detector-based gamma spectrometer in the Laboratory of Radiochemistry and Radioprotectors.

The content of calcium carbonate in the soil (according to GOST 26424-85), water-insoluble gypsum (composed of 60% $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) (GOST 26487-85), and humus (GOST 26213-91) were determined in accordance with established standards. Soil and groundwater samples were analyzed using the "MW101 PRO" pH meter, following GOST 8.857-2013.

The experimental investigations were conducted in the laboratories of the Institute of Soil Science and Agrochemistry and "Baku Landscaping Service" LLC.

VI. Analysis and Discussion

The results obtained from the studies conducted in the Caspian coastal region are presented in Table 1. As the data indicate, leaching with ordinary water, without the application of chemical ameliorants resulted in a reduction of soil salinity levels (based on total soluble salts) in the 0–50 cm layer from 2.29% to 1.18%, in the 0–100 cm layer from 2.23% to 1.60%, and in the 0–150 cm layer from 2.21% to 1.82%. At this point, the concentration of chloride anions decreased to 0.121%, 0.271%, and 0.331%, respectively, while sulfate anion concentrations were reduced to 0.60%, 0.74%, and 0.78% in the corresponding soil layers. In the treatment variant involving the application of gypsum, the degree of soil salinity, expressed in terms of total soluble salts, was reduced to 0.52% in the upper 0–50 cm layer, to 0.87% in the 0–100 cm layer, and to 1.13% in the 0–150 cm layer. Concurrently, the concentrations of chloride and sulfate anions in the respective layers decreased within the ranges of 0.041–0.025%, 0.095–0.45%, and 0.170–0.55%, indicating a measurable ameliorative effect across all soil depths assessed.

The highest leaching efficiency was observed in the treatment involving the application of a 2% dilute sulfuric acid solution. However, under this variant, effective desalinization was achieved only within the upper 0–50 cm soil layer, reaching permissible salinity thresholds. In the 0–100 cm layer, the salinity level decreased from 2.35% to 0.47%, and in the 0–150 cm layer, it was reduced from 2.33% to 0.74%, based on total soluble salts. These residual concentrations exceeded the acceptable limits by nearly twofold in the deeper layers. In this leaching treatment, the amount of chloride ions in the soil was reduced to 0.010% in the 0–50 cm layer, 0.029% in the 0–100 cm layer, and 0.066% in the 0–150 cm layer. Similarly, the sulfate ion concentrations decreased to 0.16%, 0.26%, and 0.41% at the same respective depths. These results demonstrate that the applied treatment was effective in reducing salt content throughout the soil profile.

The leaching variant involving the combined application of gypsum and dilute sulfuric acid demonstrated a high degree of consistency with the results obtained from the treatment using only dilute sulfuric acid (see Table 1).

As a result of the leaching process, notable changes were observed in the concentrations of key soil constituents. In the top 1-meter soil layer subjected to leaching with plain water, the calcium carbonate (CaCO_3) content increased slightly from 20.41% to 20.83%, while the gypsum content decreased from 0.442% to 0.283%, and the humus content declined from 0.88% to 0.80%. Additionally, the pH value of the soil solution increased from 8.99 to 9.10.

In the treatment where gypsum was applied at a rate of 20 t/ha, a reduction in calcium carbonate (CaCO_3) concentration was observed, reaching 21.15%. Conversely, the gypsum content increased from 0.622% to 0.819%. Additionally, the humus level declined from 0.81% to 0.70%, accompanied by a decrease in soil pH from 9.10 to 8.50.

Table 1: Dynamics of salinity changes in soil profiles of the Caspian coastal zone before and after leaching treatments (%)

| 0-50 cm | | | 0-100 cm | | | 0-150 cm | | |
|--|-----------------|---------------------------|----------|-----------------|---------------------------|----------|-----------------|---------------------------|
| Cl | SO ₄ | Total Soluble Salts (TSS) | Cl | SO ₄ | Total Soluble Salts (TSS) | Cl | SO ₄ | Total Soluble Salts (TSS) |
| leaching with plain water (control treatment) | | | | | | | | |
| 0.537 | 0.89 | 2.29 | 0.497 | 0.92 | 2.23 | 0.515 | 0.90 | 2.21 |
| 0.121 | 0.60 | 1.18 | 0.271 | 0.74 | 1.60 | 0.331 | 0.78 | 1.82 |
| Leaching with gypsum (20 t/ha) | | | | | | | | |
| 0.378 | 0.54 | 1.74 | 0.743 | 0.67 | 1.81 | 0.509 | 0.73 | 1.95 |
| 0.041 | 0.25 | 0.52 | 0.095 | 0.45 | 0.87 | 0.170 | 0.55 | 1.13 |
| Leaching with dilute sulfuric acid at a rate of 15 t/ha | | | | | | | | |
| 0.574 | 0.81 | 2.19 | 0.629 | 0.85 | 2.35 | 0.630 | 0.84 | 2.33 |
| 0.010 | 0.16 | 0.31 | 0.029 | 0.26 | 0.47 | 0.066 | 0.41 | 0.74 |
| Combined leaching treatment: gypsum (5 t/ha) + sulfuric acid (15 t/ha) | | | | | | | | |
| 0.392 | 0.45 | 1.36 | 0.463 | 0.65 | 1.78 | 0.496 | 0.69 | 1.89 |
| 0.02 | 0.019 | 0.38 | 0.043 | 0.30 | 0.58 | 0.108 | 0.42 | 0.85 |

The concentration of exchangeable sodium, which is a primary indicator of sodicity, was considerably lower in the treatments involving chemical ameliorants compared to the control treatment using water leaching. As illustrated in Table 2, the application of gypsum led to a decline in exchangeable sodium levels from 13.30% to 6.12%. In the treatment involving the combined application of gypsum and dilute sulfuric acid, the sodium content was reduced from 18.10% to 3.73%. Similarly, under the treatment where gypsum was applied in conjunction with dilute hydrochloric acid, the concentration dropped from 17.30% to 4.41%.

Table 2: Chemical composition of gypsum-bearing rocks from various deposits (in %) changes in the main soil components of Caspian coastal soils (0–100 cm) before and after leaching

| Parameters | | Leaching methods | | | | |
|---|----|------------------|--------|--------------------------------|--|-------|
| | | Water | Gypsum | H ₂ SO ₄ | H ₂ SO ₄ +gypsum | |
| CaCO ₃ , % | | 20.41 | 21.53 | 18.59 | 20.43 | |
| | | 20.83 | 21.15 | 16.03 | 19.77 | |
| Pure gypsum (pure calcium sulfate dihydrate (CaSO ₄ ·2H ₂ O)) | | 0.442 | 0.622 | 0.677 | 0.431 | |
| | | 0.283 | 0.819 | 1.285 | 1.168 | |
| Ph | | 8.99 | 9.10 | 8.95 | 9.10 | |
| | | 9.10 | 8.50 | 7.65 | 7.50 | |
| Humus | | 0.88 | 0.81 | 0.74 | 0.72 | |
| | | 0.80 | 0.70 | 0.67 | 0.63 | |
| Sum of exchangeable bases, mg/100eq | | 35.19 | 26.25 | 29.11 | 29.20 | |
| | | 34.90 | 36.61 | 35.16 | 32.66 | |
| Percentage composition of individual exchangeable cations: | Ca | | 66.58 | 57.52 | 62.59 | 64.08 |
| | | | 57.05 | 61.95 | 71.50 | 75.90 |
| | Mg | | 21.26 | 29.18 | 19.31 | 18.63 |
| | | | 30.06 | 31.33 | 24.77 | 19.69 |
| | Na | | 12.16 | 13.30 | 18.10 | 17.30 |
| | | | 12.89 | 6.12 | 3.73 | 4.41 |

The highest ameliorative efficiency in the experiments conducted in the Karabakh plain was achieved through the combined application of gypsum and dilute mineral acid solutions.

Following the completion of the leaching process, chemical analysis of the subsequently collected soil samples indicated that the salinity level in the top 0–40 cm soil layer decreased significantly. In the treatment configuration combining gypsum with 1% sulfuric acid, the total soluble salt content was reduced from 2.00% to 0.20%. Similarly, in the configuration involving gypsum combined with 0.5% hydrochloric acid, the salinity level declined from 2.91% to 0.20%. As a result of leaching, the salinity level in the one-meter soil layer decreased to 0.28% and 0.24% (based on total soluble salts), depending on the treatment configurations applied. In the 0–150 cm layer, the salinity was reduced to 0.30% in both cases. In the configuration combining gypsum with 1% sulfuric acid, the chloride ion concentration across all layers was reduced to 0.02%, while the sulfate ion concentration was recorded at 0.11%, 0.15%, and 0.18%, respectively. In the alternative treatment configuration involving gypsum combined with 0.5% hydrochloric acid, the chloride ion concentrations across the respective soil profile layers were recorded at 0.03%, 0.04%, and 0.04%, while the sulfate ion concentrations were measured at 0.11%, 0.15%, and 0.18%, respectively (Table 3).

The ameliorative effect of leaching with plain water in the Karabakh region was also found to be very low. Specifically, in this treatment approach, the overall salinity level of the soil decreased from 2.50% to 0.78% in the top 40 cm layer, from 2.30% to 1.28% in the one-meter layer, and from 2.15% to 1.50% in the 1.5-meter layer. The chloride ion concentration across the layers was reduced to 0.11%, 0.12%, and 0.12%, while the sulfate ion concentration was approximately 0.42%, 0.74%, and 0.78%, respectively.

When gypsum was used in combination with mineral acids, the salinity level in the soil profile was reduced to an acceptable threshold of 0.3% up to a depth of 150 cm. However, when applied alone at rates of 5, 10, and 15 tons per hectare, the ameliorative effect was observed only in the top 40 cm layer, where the salinity levels decreased to 0.47%, 0.36%, and 0.29%, respectively, in line with the application rates. In the top layer, the chloride ion concentration was reduced to 0.11%, 0.08%, and 0.05%, while the sulfate ion concentration decreased to 0.29%, 0.21%, and 0.18%, respectively, according to the applied treatment rates (Table 3).

The effectiveness of the leaching process with gypsum diminished in the deeper soil layers. The remaining salt content in the top 0–100 cm layer decreased to 0.67%, 0.58%, and 0.60%, while in the 0–140 cm layer, it was reduced to 0.74%, 0.70%, and 0.69%. For the treatment with 5 tons of gypsum per hectare, the chloride ion concentration in the 0–140 cm soil layer dropped to 0.11%, and the sulfate ion concentration decreased to 0.29%. In the 0–140 cm depth, the reduction was observed at 0.13% and 0.86%, respectively. When 10 tons of gypsum per hectare were applied, the chloride concentration in the one-meter layer was reduced to 0.10%, and the sulfate concentration was reduced to 0.24%. For the 0–140 cm depth, these values were 0.12% and 0.29%, respectively. Finally, in the treatment with 15 tons of gypsum per hectare, the remaining salt content in the one-meter soil layer was 0.60%, and in the 0–140 cm layer, it was 0.69% (Table 3).

During the experiments conducted in the Karabakh plain, the impact of leaching on the primary chemical elements of the soil was also investigated. The results of the study indicated that after leaching with plain water, the calcium carbonate content in the top one-meter soil layer increased from 10.34% to 11.20%, while the gypsum content decreased from 0.27% to 0.21%. The amount of exchangeable calcium (Ca) cations decreased from 64.27% to 55.70%, while the magnesium (Mg) cation concentration increased from 27.13% to 34.80%, and the sodium (Na) cation concentration rose from 8.60% to 9.50%. During the experiments conducted in the Karabakh plain, the impact of leaching on the primary chemical elements of the soil was also investigated.

Table 3: The dynamics of salinity variation across soil horizons in the Karabakh plain following leaching, expressed as percentage values.

| Depth, cm | Parameters | Without ameliorants | Meliorantla | | | | |
|-----------|---------------------------|---------------------|---------------|--------------|--------------|--|--------------|
| | | | Gypsum | | | Gypsum +H ₂ SO ₄ | Gypsum +HCl |
| | | | 5 | 10 | 15 | 5+10 | 5+10 |
| 0-40 | Total Soluble Salts (TSS) | 2.50 0.78 | 2.00 0.47 | 2.36 0.36 | 2.72 0.29 | 2.00 0.20 | 2.91 0.20 |
| | Cl | 0.50 0.11 | 0.88 0.11 | 0.32 0.08 | 0.51 0.05 | 0.56 0.02 | 0.87 0.03 |
| 0-100 | SO ₄ | 0.70 0.42 | 0.90 0.29 | 0.70 0.21 | 1.28 0.18 | 0.63 0.09 | 0.30 0.11 |
| | Total Soluble Salts (TSS) | 2.30 1.28 | 1.993 0.67 | 2.32 0.58 | 2.32 0.60 | 2.10 0.28 | 2.65 0.24 |
| 0-140 | Cl | 0.48 0.12 | 0.86 0.12 | 2.64 0.10 | 0.38 0.06 | 0.54 0.02 | 0.70 0.04 |
| | SO ₄ | 0.66 0.47 | 0.82 0.83 | 0.80 0.24 | 1.25 0.32 | 0.74 0.15 | 0.98 0.15 |
| | Total Soluble Salts (TSS) | 2.15 1.50 | 1.90 0.74 | 2.52 0.70 | 2.11 0.69 | 2.11 0.30 | 2.50 0.30 |
| | Cl | 0.43 0.12 | 0.35 0.13 | 0.76 0.12 | 0.33 0.07 | 0.50 0.02 | 0.62 0.04 |
| | SO ₄ | 0.73 0.78 | 0.80 0.86 | 0.65 0.29 | 1.12 0.39 | 0.79 0.18 | 1.00 0.18 |

Table 4: The Change in the Main Elemental Composition of Karabakh Saline Soils After Leaching (0-100 cm Layer)

| Parameters | Without ameliorants | With ameliorant | | | | |
|---|---------------------|-----------------|-------|-------|---------------------------------------|-------------|
| | | Gypsum | | | gypsum+H ₂ SO ₄ | gypsum +HCl |
| | | 5 | 10 | 15 | 5+10 | 5+10 |
| CaCO ₃ , in % | 10.34 | 12.38 | 12.56 | 11.91 | 12.90 | 13.00 |
| | 11.20 | 12.48 | 13.66 | 12.90 | 9.75 | 10.36 |
| Pure gypsum (pure calcium sulfate dihydrate (CaSO ₄ ·2H ₂ O)) | 0.27 | 0.24 | 0.25 | 0.33 | 0.134 | 0.28 |
| | 0.21 | 0.20 | 0.237 | 0.36 | 0.91 | 0.53 |
| Sum of exchangeable bases, mg/100eq | 31.14 | 25.42 | 30.87 | 21.37 | 29.20 | 25.37 |
| | 31.65 | 28.18 | 28.61 | 27.47 | 29.37 | 28.80 |
| percentage of the total | | | | | | |
| Ca | 64.27 | 59.57 | 57.05 | 55.07 | 57.72 | 60.15 |
| | 55.70 | 61.02 | 61.58 | 59.17 | 71.17 | 67.05 |
| Mg | 27.13 | 32.13 | 32.95 | 34.47 | 28.93 | 27.70 |
| | 34.80 | 30.88 | 31.98 | 34.23 | 23.80 | 26.95 |
| Na | 8.60 | 8.30 | 10.00 | 10.46 | 13.35 | 12.15 |
| | 9.50 | 8.10 | 7.14 | 6.60 | 5.03 | 6.00 |

The results of the study indicated that after leaching with plain water, the calcium carbonate content in the top one-meter soil layer increased from 10.34% to 11.20%, while the gypsum content decreased from 0.27% to 0.21%. The amount of exchangeable calcium (Ca) cations decreased from 64.27% to 55.70%, while the magnesium (Mg) cation concentration increased from 27.13% to 34.80%, and the sodium (Na) cation concentration rose from 8.60% to 9.50%. As a result of leaching, the

indicators of the primary chemical elements in the soil showed that treatment configurations involving the combined application of ameliorants were more effective than those using gypsum alone. According to the analysis data, when gypsum was used in combination with a sulfuric acid solution, the concentration of exchangeable sodium (Na) decreased from 13.35% to 5.03%, while in the treatment with a 0.5% hydrochloric acid solution, the concentration of sodium was reduced from 12.15% to 6.00%. This resulted in nearly complete elimination of salinity (Table 4).

VII. Conclusion

The findings derived from the conducted research leads to the following conclusions.

1. The soils in both regions under investigation exhibit a heavy texture and are highly saline, with moderate levels of sodicity.
2. Chemical amelioration methods should be applied for the improvement of soils in both the Caspian coastal zone and the Karabakh region.
3. During soil amelioration practices, the use of weak acid solutions combined with gypsum as part of the chemical amelioration process is considered optimal.
4. It is recommended that the dosage of chemical ameliorants used in the treatment of regional soils range between 10-15 tons per hectare, with the optimal leaching rate being 15,000 m³/ha.

CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

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