DOI Link: https://doi.org/10.61586/hCyNl
Vol.43, Issue.8, Part.1, August 2025, PP.36-49

APPLICATION OF BRANDY INDUSTRY WASTE FOR RECLAMATION OF SALINE-SODIC SOILS

Samvel Sahakyan , Tatevik Yedoyan[1] Arestak Sarukhanyan[1], Armine Baghdagyulyan[1], Qrıstıne Tovmasyan[1], Pargev Baljyan[1]*

[1]*National University of Architecture and Construction of Armenia, 105 Teryan st., Yerevan 0009, Republic of Armenia*
***Corresponding author:** Tatevik Yedoyan, yedoyantatevik@nuaca.am

Received June 2025 Accepted July 2025 Published August 2025

ABSTRACT

The rapid expansion of global brandy production has heightened environmental concerns regarding the disposal of distillery dregs, particularly when these wastes are discharged into surface waters. However, distillery dregs are rich in valuable constituents such as organic acids (75–104 mmol L^{-1}), making them a promising chemical ameliorant for the reclamation of saline-sodic soils. This study investigates the potential of utilizing brandy industry by-products to improve soil properties, with the dual objectives of determining effective application rates and addressing waste management challenges. Field experiments were conducted in 2023 on saline-sodic soils covering an area of 1,280 m^2. Treatments involved applying 50%, 75%, and 100% of the calculated distillery dreg application rate. The results indicated that the optimal treatment, consisting of 14,600 t ha^{-1} of distillery dregs combined with 5,000 m^3 ha^{-1} of leaching water, effectively reduced soil salinity and alkalinity to acceptable levels. To enhance economic feasibility and minimize transportation costs, it is recommended that distillery dregs be concentrated fivefold at the production site prior to field application. Overall, these findings highlight the dual environmental and agronomic benefits of employing distillery dregs for the sustainable reclamation of saline-sodic soils while promoting responsible management of brandy industry residues.

***Keywords**: distillery dreg, ameliorant application rate, soil desalination and dealkalization, soil chemical properties, soil improvement*

1. INTRODUCTION

The intensification of industrial production has generated vast amounts of organic waste, raising serious concerns about environmental sustainability. Addressing this challenge requires reducing waste volumes and promoting their reuse across economic sectors, particularly in agriculture, to improve resource efficiency (Duque-Acevedo et al., 2020). Understanding how production wastes interact with soils is crucial to evaluate their agricultural potential and the associated environmental and economic benefits.

Many strategies have been proposed for reusing industrial and agricultural wastes (Dinnar et al., 2022). However, their application in soil improvement is often limited by toxic elements that degrade soil quality, contaminate water, and pose risks to human health (Ahmed et al., 2017). This has driven interest in wastes with beneficial properties, especially those rich in organic acids. Organic acids can promote ion exchange, improve soil structure, and reduce alkalinity, making them valuable for soil remediation. Despite this potential, few studies have examined organic acid-containing wastes for reclaiming saline and alkaline soils (Demis, 2022; Gasparyan et al., 2024).

Shifting agriculture toward a circular, waste-based model has become a global priority (Maina et al., 2017). Agriculture alone generates around 570 million tonnes of waste annually (Sherwood, 2020). Reclaiming saline and alkaline soils, which is essential for restoring land productivity, typically relies on chemical ameliorants such as sulfuric acid, iron sulfate, and phosphogypsum. Replacing these synthetic inputs with suitable organic wastes could reduce pollution, lower costs, and promote sustainable soil management (Toop et al., 2020). Biological ameliorants, or biomeliorants, offer further advantages by enhancing soil fertility through nutrient enrichment and improving soil physical and chemical properties (Ranta et al., 2021).

Among the promising sources of biomeliorants are liquid organic wastes rich in organic acids. One such material, distillery waste, commonly referred to as distillery dregs (DD) is a dark brown acidic liquid with a pH of 3.1–3.4, containing up to 5.647 g L^{-1} of organic acids. These include tartaric acid (70%), malic acid (25%), and acetic acid (5%), with a total titratable acidity of 104 mmol L^{-1}.

In countries with significant alcohol and spirits industries, large volumes of this waste are generated annually. In Armenia, for instance, about 100,000 tonnes are produced annually, much of which is discharged into surface waters. This practice severely damages aquatic ecosystems due to the waste's high temperature (90–95 °C) and low transparency, which reduce oxygen solubility and block photosynthesis, harming aquatic flora and fauna (Bezuneh and Kebede, 2015; FitzGibbon et al., 1998). To address this, many countries have introduced regulations prohibiting direct disposal of distillery waste into natural water bodies (Fillaudeau et al., 2008).

Several technologies have been developed to address this issue while simultaneously generating economic benefits (Mikucka et al., 2022), including anaerobic fermentation for methane production (España-Gamboa et al., 2011), electrodialysis for the extraction of valuable organic acids (Gurreri et al., 2020), and distillation to concentrate the waste and recover usable components (Halvorsen and Skogestad, 2011). A comparative analysis of these technologies suggests that distillation is the most effective method for DD condensation, as it separates the stillage into water and concentrated DD matter, thereby ensuring the near-complete preservation of its components. The primary drawback of distillation lies in its high energy consumption (Kooijma and Sorensen, 2022). Nevertheless, integrating energy generated during the brandy distillation process can offset these energy demands, enabling DD condensation without incurring additional financial costs (Sahakyan et al., 2023).

Soil salinization and alkalization continue to pose a major threat to agricultural productivity, affecting over 581 million hectares globally across more than 100 countries (Kumar and Sharma, 2020). In Armenia, the Ararat Plain contains approximately 24,500 hectares of saline-sodic soils that remain uncultivated due to degradation. Traditional reclamation methods rely on imported chemical ameliorants, such as sulfuric acid and iron sulfate. For instance, the Research Center for Soil Science, Agrochemistry, and Amelioration of Armenia successfully restored 5,500 hectares of saline-sodic soils using these imported materials (Petrosyan, 1982). However, the rising costs and logistical challenges of transporting such chemicals have made their continued use unsustainable, prompting the search for cost-effective, locally available alternatives.

This study aims to investigate the potential of using DD as a chemical ameliorant for the reclamation of saline-sodic soils. The objectives include determining optimal application rates, analyzing changes in soil chemical properties, and improving the overall efficiency of the reclamation process. The novelty of this research lies in its comprehensive examination of the interactions between distillery waste and alkaline soil systems, offering a dual solution to both waste management and land restoration challenges.

2. MATERIAL AND METHODS

2.1 Study Site and Soil Characterization

The field experiment was conducted in 2023 on a 1,280 m^2 plot of saline-sodic soils in the Mrgashat community of the Armavir region, Armenia. Mrgashat was selected for its representative soil degradation and its importance to local agricultural productivity. The experimental field was divided by earthen bunds into three treatment plots (hereafter referred to as Checks) with surface areas of 440 m^2, 420 m^2, and 420 m^2, respectively (Figure 1).

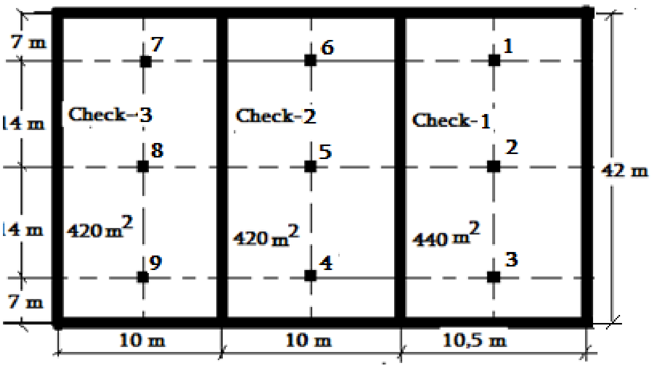

Figure 1. Layout of the experimental treatment plots (Checks).

Soil samples were collected from three points within each Check at four depth intervals: 0–25 cm, 25–50 cm, 50–75 cm, and 75–100 cm. These samples were analyzed to determine the chemical composition of soluble salts and to calculate the required dosage of the ameliorant. In the 0–100 cm soil layer, total soluble salt content ranged from 0.5% to 1.5%, and soda content varied between 1.5 and 6.0 cmol kg^{-1}. The soils were strongly alkaline, with pH values between 8.9 and 10.2. Exchangeable sodium levels ranged from 12 to 25 cmolc kg^{-1}, while the exchangeable sodium percentage (ESP) was between 40% and 83%. Groundwater was observed at a depth of 175–200 cm, with a mineralization range of 1.784–2.668 g L^{-1}.

2.2 Experimental Design

To evaluate the efficacy of distillery dregs (DD) as a chemical ameliorant, three dosage levels were applied to Checks 1, 2, and 3, corresponding to 50%, 75%, and 100% of the calculated requirement, respectively. The treatments were as follows:

1. Treatment 1 (Check 1): 50% of the calculated DD dose
2. Treatment 2 (Check 2): 75% of the calculated DD dose
3. Treatment 3 (Check 3): 100% of the calculated DD dose

A control (untreated) treatment was not included, as previous research has demonstrated that water leaching alone is ineffective for reclaiming saline-sodic soils.

2.3 Calculation of Ameliorant Dosage

The required dosage of DD was determined using the methodology established in the Armenian reclamation manual (Petrosyan, 1982), according to the following formula:

$$S = k(M - d) \qquad (1),$$

where:
S is the ameliorant dose, t ha^{-1},
M is the sum of total alkalinity (HCO_3^-) and exchangeable natrium (Na^+), cmol kg^{-1},
d indicates the permissible level of exchangeable sodium, 3 cmolc kg^{-1},

k represents the conversion coefficient indicating the amount of ameliorant required to neutralize 1 cmolc kg^{-1} of total alkalinity within the top 100 cm of soil over one hectare.

Given the acidity of DD (104 mmol L^{-1}), the conversion coefficient (k) was set to 1100 t ha^{-1}. Thus, the full recommended dose of DD was calculated as 14,600 t ha^{-1}, to be applied together with 5,000 m^3 ha^{-1} of leaching water.

Accordingly, the volumes of DD applied in the three treatments were 317 m^3, 432 m^3, and 614 m^3, respectively, while the volume of leaching water remained constant at 216 m^3 across all treatments (Table 1).

Table 1. Calculation of the required norms of DD for the reclamation of saline-sodic soils according to experimental treatments

Treat-ment	№ of Checks	№ of sections	Exch. Na, M – d, cmolc kg^{-1}	DD require-ment K, t ha^{-1}	Total DD per site for 100% norm t/site	% of calculated norm	Applied DD, t
I	Check-1 (440 m^2)	1 2 3 *Average*	9.6 16.3 13.3 *13.1*	1100	634	50	317
II	Check-2 (420 m^2)	4 5 6 *Average*	10.7 14.1 12.6 *12.5*	1100	577	75	432
III	Check-3 (420 m^2)	7 8 9 *Average*	16.0 12.3 11.5 *13.3*	1100	614	100	614

2.4 Ameliorative Mechanism of DD

The ameliorative effect of DD is primarily attributed to its high concentration of organic acids, which interact with alkaline soil constituents to lower pH and facilitate sodium removal through a series of chemical reactions:

$H_2C_4H_4O_6 + Na_2CO_3\ (NaHCO_3) \rightarrow Na_2C_4H_4O_6 + H_2O + CO_2$ (I),

$H_2C_4H_4O_6 + CaCO_3\ (MgCO_3) \rightarrow CaC_4H_4O_6\ (MgC_4H_4O_6) + H_2O + CO_2$ (II),

$CaC_4H_4O_6\ (MgC_4H_4O_6) + CEC^{Na} \rightarrow Na_2C_4H_4O_6 + CEC^{Ca(Mg)}$ (III).

Reaction *1* neutralizes sodium carbonate, Reaction *2* transforms calcium carbonate to calcium tartrate, and Reaction *3* displaces exchangeable sodium from the CEC.

Previous research (Oganesyan, 1988) has shown that partial doses (50–75%) of acid-based ameliorants such as sulfuric acid and iron sulfate can be as effective as full doses. To test whether this holds true for DD, the current study incorporated reduced-dose treatments (Treatments I and II) for comparative evaluation.

3. RESULTS AND DISCUSSION

3.1 Application of 50% of the Calculated DD Dose

Chemical analysis of soils treated with 50% of the calculated dose of DD is summarized in Table 2. In the top 0–25 cm layer, total soluble salt content was reduced from 0.835% to 0.304%, and sodium carbonate (CO_3^{-2}) was fully neutralized.

Table 2. Water-extractable chemical properties of saline-sodic soil before and after reclamation using 50% of the calculated DD dose

Depth, cm	Total Salts, %	pH	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+
			cmol kg^{-1}						
Before reclamation									
0-25	0.835	9.3	2.00	2.80	5.70	3.81	0.95	0.16	11.20
25-50	0.890	9.8	2.79	3.48	6.40	3.18	0.50	0.08	12.50
50-75	0.678	10.0	2.56	3.48	5.20	1.25	0.65	0.48	8.80
75-100	0.404	10.0	2.00	3.28	2.20	1.08	0.40	0.40	4.76
After reclamation									
0-25	0.304	7.2	0.00	2.20	0.73	1.16	0.70	0.40	2.99
25-50	0.505	8.3	0.20	5.12	0.73	0.51	0.25	0.24	5.87
50-75	0.676	9.3	0.63	6.40	1.61	0.67	0.35	0.16	8.17
75-100	0.621	9.0	0.40	6.00	0.99	0.87	0.35	0.16	7.35

In the 25–75 cm depth interval, total soluble salts ranged from 0.505% to 0.676%, while soda concentrations ranged from 0.20 to 0.63 cmol kg^{-1}, indicating partial but incomplete amelioration. Chloride and sulfate concentrations were effectively leached throughout the 0–100 cm soil profile, with values not exceeding 1.61 cmol kg^{-1}, falling within permissible limits (≤1.5 cmol kg^{-1}).

The concentration of water-soluble sodium decreased significantly following chemical reclamation, from an initial range of 4.76 to 12.50 mmol kg^{-1} to 2.99 to 8.17 mmol kg^{-1}. However, as illustrated in Figure 2, the applied ameliorant dose was insufficient to fully displace exchangeable sodium from the cation exchange complex (CEC). A notable reduction in exchangeable sodium was observed only in the upper 0–25 cm soil layer, where its content declined from 14.0 to 5.7 cmolc kg^{-1}. In contrast, in the 50–75 cm layer, the reduction was minimal, approximately 2 cmolc kg^{-1}, indicating limited reclamation efficiency at greater depths.

Soil pH in the upper 0–50 cm layer decreased significantly, ranging from 7.2 to 8.3 post-treatment, which is within the permissible range. However, the lower 50–100 cm layer retained high alkalinity, with pH values ranging from 8.8 to 9.3. A substantial decrease in exchangeable sodium (from 13.8 to 5.7 cmolc kg^{-1}) occurred only in the surface 0–25 cm layer. Reductions in deeper layers were minor, suggesting limited downward movement of the ameliorant and reaction products.

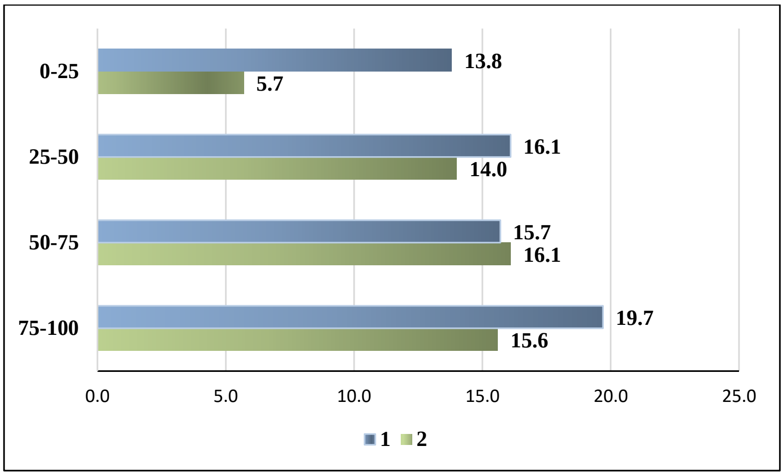

Figure 2. Exchangeable sodium content (cmolc kg^{-1}) in soil layers (cm) before and after chemical reclamation of saline-sodic soils using 50% of the calculated DD dose:

1 – Before reclamation, 2 – After reclamation

These findings suggest that applying 50% of the calculated DD dose resulted in effective desalination and dealkalization of the surface layer (0–25 cm), but deeper layers (25–100 cm) remained saline and sodic, with elevated exchangeable sodium and pH. Therefore, full-profile reclamation of saline-sodic soils to a depth of 100 cm will require the application of the full DD dose along with enhanced leaching to remove residual sodium and soluble salts from the subsoil.

3.2 Application of 75% of the Calculated DD Dose

The results of the chemical analyses (Table 3) indicate that the application of 75% of the calculated DD dose led to the neutralization of soda in the 0–75 cm soil layer. In the 75–100 cm layer, soda content was reduced to below 0.2 cmol kg^{-1}. Water-soluble sodium levels across the 0–100 cm profile also decreased significantly, from an initial range of 13.4–18.0 to 3.33–5.00 cmol kg^{-1} after chemical treatment and leaching. However, these values remained above the permissible threshold.

Table 3. Water-extractable chemical properties of saline-sodic soil before and after reclamation using 75% of the calculated DD dose

Depth, cm	Total salts, %	pH	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	Exch. Na^+
			cmol kg^{-1}							
			Before reclamation							
0-25	1.278	10.0	0.20	4.28	6.01	8.11	1.30	0.48	16.62	16.4
25-50	1.405	10.3	0.79	7.20	7.28	5.40	1.40	0.48	18.00	14.8
50-75	1.205	10.4	0.79	7.28	7.60	2.18	0.80	0.24	16.20	19.0
75-100	1.120	10.5	2.56	5.88	5.27	3.20	0.45	0.40	13.40	18.0
			After reclamation							
0-25	0.505	8.0	0.00	3.80	0.51	2.33	1.00	0.64	5.00	2.0
25-50	0.372	7.8	0.00	2.53	0.31	2.14	0.85	0.80	3.33	3.9
50-75	0.409	8.3	0.00	4.00	0.20	0.93	0.30	0.40	4.43	6.6
75-100	0.420	8.3	0.00	4.00	0.20	1.08	0.30	0.32	4.66	8.0

Total soluble salt concentrations decreased from 1.12–1.41% to 0.372–0.505%, yet still exceeded the acceptable limit of 0.25%, indicating the continued need for leaching. Soil pH values showed a marked improvement, decreasing from 10.0–10.5 to a range of 7.7–8.3 across the entire 0–100 cm profile.

Exchangeable sodium content in the 0–50 cm layer dropped substantially, from 14–16 to 1.7–3.6 cmolc kg^{-1}, indicating successful dealkalization in this zone. However, in the 50–100 cm layer, exchangeable sodium remained above acceptable levels, ranging from 6.0 to 8.0 cmolc kg^{-1} (Figure 3).

These results suggest that applying 75% of the calculated DD dose effectively ameliorates the upper 0–50 cm of soil but fails to sufficiently reclaim the deeper layers. Full-profile reclamation of the 0–100 cm soil layer requires the application of the full DD dose along with additional leaching to remove residual salts and exchangeable sodium from the subsoil.

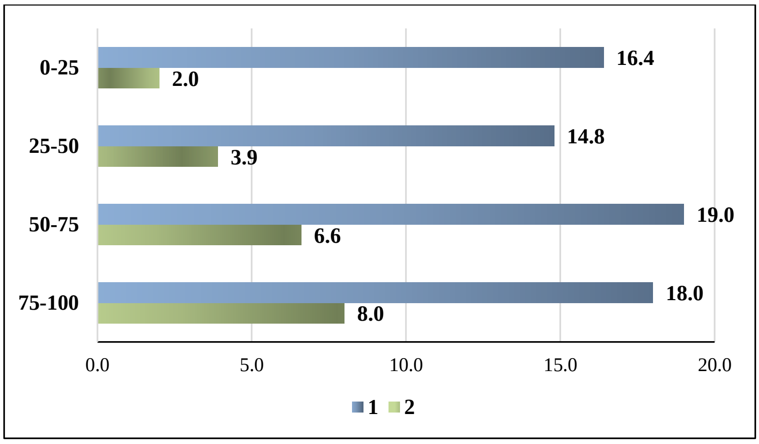

Figure 3. Exchangeable sodium content (cmolc kg^{-1}) in soil layers (cm) before and after chemical reclamation of saline-sodic soils using 75% of the calculated DD dose: *1 – Before reclamation, 2 – After reclamation*

3.3 Application of 100% of the Calculated DD Dose

The results of chemical analyses using the full calculated dose of DD are presented in Table 4. In the 0–100 cm soil layer, soda was completely neutralized, chlorides were largely leached out, and their concentrations fell within permissible limits.

Table 4. Water-extractable chemical properties of saline-sodic soil before and after reclamation using 100% of the calculated DD dose

Depth, cm	Total Salts, %	pH	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	Exch. Na^+
			cmol kg^{-1}							
			Before reclamation							
0-25	1.539	10.2	2.42	5.56	7.88	8.67	0.85	0.32	20.94	14.6
25-50	0.705	9.4	1.56	4.89	4.48	0.60	0.30	0.88	8.76	15.5
50-75	0.983	9.3	1.24	6.08	5.89	1.93	0.70	0.72	12.48	10.0
75-100	0.603	9.1	0.87	4.40	3.16	0.85	0.45	0.96	7.00	9.2
			After chemical reclamation							
0-25	0.168	7.8	0.00	1.2	0.28	0.65	0.55	1.36	1.12	1.5
25-50	0.179	7.6	0.00	1.48	0.28	0.72	0.90	0.88	0.70	1.8
50-75	0.265	7.6	0.00	2.67	0.37	0.45	1.05	0.96	1.48	1.9
75-100	0.243	7.5	0.00	3.20	0.48	0.15	0.90	1.04	1.89	2.4

Water-soluble sodium levels decreased significantly from 7.00–20.94 to 0.70–1.89 cmol kg^{-1} after chemical reclamation and leaching (Figure 4). Total water-soluble salts declined from an initial range of 0.606–1.539% to 0.168–0.265%.

Soil pH values across the 0–100 cm layer stabilized within acceptable limits, ranging from 7.4 to 7.8. Exchangeable sodium content decreased from 9.2–15.5 to 1.5–2.4 cmolc kg^{-1}.

These results demonstrate that 100% of the calculated DD dose, combined with adequate leaching, fully reclaims the saline-sodic soil profile to a 100 cm depth.

Contrary to earlier findings (Oganesyan, 1988), our data indicate that partial doses (50–75%) are insufficient to achieve full reclamation.

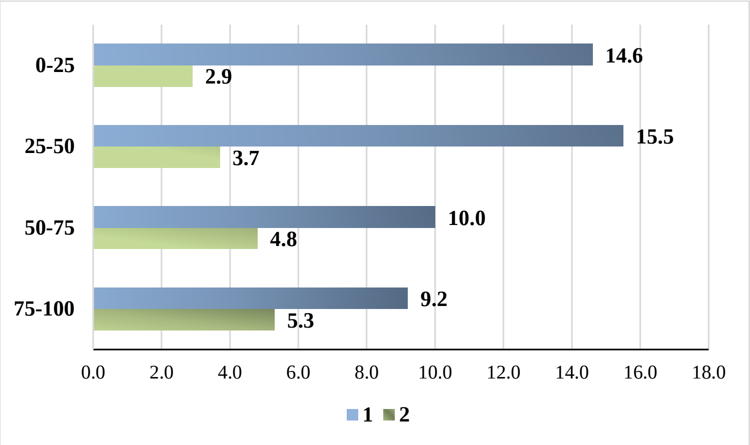

Figure 4. Exchangeable sodium content (cmolc kg^{-1}) in soil layers (cm) before and after chemical reclamation of saline-sodic soils using 100% of the calculated DD dose: *1 – Before reclamation, 2 – After reclamation*

3.4 Mechanisms of DD Interaction with Soil

The application of DD initiates neutralization of the alkaline soil solution due to the presence of tartaric acid. Upon contact with soil carbonates, tartaric acid reacts to form calcium and magnesium tartrates. Although calcium tartrate is poorly soluble, its slow formation allows tartaric acid to persist in the soil, maintaining an acidic environment that facilitates further reactions. This process results in increased concentrations of soluble calcium (20–25 mmol L^{-1}), which displaces exchangeable sodium from the CEC. The displaced sodium forms soluble sodium tartrate, which is subsequently leached from the soil profile through drainage system.

The results of these chemical transformations are presented in Table 5, which shows the changes in carbonate content and the composition of exchangeable cations across the 0–100 cm soil profile following the application of 100% of the calculated DD dose.

Table 5. Changes in carbonate content and exchangeable cations in saline-sodic soil before (I) and after (II) reclamation using 100% of the calculated DD dose

Depth, cm	Carbonate content in saline-sodic soils, %				Exchangeable cations, % of CEC			
	$CaCO_3$		**$MgCO_3$**		**Ca**	**Mg**	**Na**	**K**
	I	II	I	II		II		
0-25	10.0	9.6	2.8	2.4	56.3	33.1	5.4	5.2
25-50	11.4	10.3	2.7	2.7	53.3	37.7	4.2	4.8
50-75	10.0	9.4	2.7	2.9	61.7	29.7	1.8	6.8
75-100	10.0	9.7	2.8	2.8	59.2	32.6	4.5	3.7
Average 0-100	10.4	9.8	2.8	2.7	57.6	33.3	4.0	5.1

The application of 100% of the calculated DD dose reduced calcium carbonate content by 0.6% and magnesium carbonate by 0.1% across the 0–100 cm soil layer. Post-reclamation analysis showed an increase in exchangeable calcium and magnesium in the CEC, from 53.3% to 61.1% and from 29.7% to 37.7%, respectively. The combined proportion of exchangeable sodium and potassium remained below 10% of the CEC, which is within acceptable limits, indicating successful dealkalization of the soil.

Unlike conventional ameliorants such as sulfuric acid or iron sulfate, which act primarily in the surface layer and risk gypsum accumulation, DD penetrates more deeply and maintains permeability. This makes it particularly advantageous when used prior to gypsum application, establishing a filtration path that enhances gypsum efficacy in saline-sodic soils.

3.5 Economic Consideration

The primary limitation of DD use is transportation cost. However, condensing DD at the distillery can reduce these costs significantly. For example, transporting 14,600 tonnes of uncondensed DD over 15 km costs approximately USD 17,520. If condensed fivefold, transport costs can be reduced to USD 3,504 (Sahakyan et al., 2023). This underscores the potential of DD as a scalable, cost-effective ameliorant for widespread soil reclamation.

CONCLUSION

This study conclusively demonstrates that distillery dregs (DD) are an effective and scalable amendment for the chemical reclamation of saline-sodic soils. Incremental application of 50%, 75%, and 100% of the calculated DD dose enabled progressive reclamation of the 0–25 cm, 0–50 cm, and full 0–100 cm soil profiles, respectively. Full-profile remediation was achieved using 14.6 t ha^{-1} of DD in combination with 5,000 m^3 ha^{-1} of leaching water.

The chemical mechanism underlying soil improvement was clearly established: tartaric acid in DD initiated sustained acidification, promoting the gradual dissolution of native calcium and magnesium carbonates (by 0.6% and 0.1%, respectively). This, in turn, elevated soluble calcium concentrations (20–25 mmol L^{-1}), effectively displacing sodium from the cation exchange complex (CEC). The displaced sodium, in the form of sodium tartrate, was efficiently leached from the soil, resulting in significant and stable reductions in exchangeable sodium across the profile.

While transportation cost remains the primary constraint, condensing DD at the production site can reduce this burden by up to fivefold. Furthermore, condensed DD may be used either as a standalone ameliorant or in synergy with gypsum to enhance its solubility and deepen its effectiveness.

Overall, the results highlight DD as a cost-effective, environmentally sustainable, and technically viable solution for large-scale reclamation of saline-sodic soils. Its integration into combined treatment strategies offers a promising pathway for long-term soil productivity restoration in affected regions.

REFERENCES

Ahmed M., Rauf M., Mukhtar Z., Ahmad S.N. (2017). Excessive use of nitrogenous fertilizers: An unawareness causing serious threats to environment and human health. *Environmental Science and Pollution Research*, 24, 26983–26987. https://doi.org/10.1007/s11356-017-0589-7

Bezuneh T.T., Kebede E.M. (2015). Physicochemical characterization of distillery effluent from one of the distilleries found in Addis Ababa. Ethiopia. J*ournal of Environment and Earth Science*, 5(11), 41–47. https://www.researchgate.net/publication/282752574

Demis A.F. (2022). Reclamation of a saline-sodic soil with organic amendments and leaching. *Environmental Sciences Proceedings*, 16, 56. https://doi.org/10.3390/environsciproc2022016056

Dinnar S.H., Islam S., Singh M., Gaba R. (2022). Future-oriented waste management technology for Ward-6. Bogura. Bangladesh – A step towards sustainability. *Geomatics and Environmental Engineering*, 16(1), 5–15. https://doi.org/10.7494/geom.2022.16.1.5

Duque-Acevedo M., Belmonte-Ureña L.J., Cortés-García F.J., Camacho Ferre F. (2020). Agricultural waste: Review of the evolution. approaches and perspectives on alternative uses. *Global Ecology and Conservation*, 22, e00902. https://doi.org/10.1016/j.gecco.2020.e00902

España-Gamboa E., Mijangos-Cortes J., Barahona-Perez L., Dominguez-Maldonado J., Hernández-Zarate G., Alzate-Gaviria L. (2011). Vinasses: characterization and treatments. *Waste Management & Research*, 29 (12), 1235–1250. https://doi.org/10.1177/0734242X10387313

Fillaudeau L., Bories A., Decloux M. (2008). Brewing. winemaking and distilling: an overview of wastewater treatment and utilization schemes. [in:] Klemeš J.. Smith R.. Kim J.-K. (eds.). Handbook of Water and Energy Management in Food Processing. Woodhead Limited. Cambridge. UK, 929–995. https://doi.org/10.1533/9781845694678.6.929

FitzGibbon F., Singh D., McMullan G., Marchant R. (1998). The effect of phenolic acids and molasses spent wash concentrations of distillery wastewater remediation by fungi. *Process Biochemistry*, 33(8), 799–803. https://doi.org/10.1016/S0032-9592(98)00050-8

Gasparyan G., Eloyan A., Jhangiryan T., Markosyan A., Beglaryan I., Barseghyan M. (2025). Wheat production management in saline soils through the use of vinasse. *Functional Food Science*, 5(1), 20-29. https://doi.org/10.31989/ffs.v5i1.1539

Gurreri L., Tamburini A., Cipollina A., Micale G. (2020). Electrodialysis Applications in wastewater treatment for environmental protection and resources recovery: A systematic review on progress and perspectives. *Membranes*, 10(7), 146. https://doi.org/10.3390/membranes10070146

Halvorsen I., Skogestad S. (2011). Energy efficient distillation. *Journal of Natural Gas Science and Engineering, 3(4), 571-580.* https://doi.org/10.1016/ j.jngse.2011.06.002

Kooijman H.A., Sorensen E. (2022). Recent advances and future perspectives on more sustainable and energy efficient distillation processes. *Chemical Engineering Research and Design*, 188, 473-482. https://doi.org/10.1016/j.cherd.2022.10.005

Kumar P., Sharma P.K. (2020). Soil salinity and food security in India. *Frontiers in Sustainable Food Systems, 4*, 533781. https://doi.org/10.3389/fsufs.2020.533781

Oganesyan. A.S. (1988). Comparative ameliorative efficiency of various doses of anhydrous iron sulphate. *Proceedings of Research Institute of Soil and Agrochemistry*, 8, 133-139.

Maina S., Kachrimanidou V., Koutinas A. (2017). A roadmap towards a circular and sustainable bioeconomy through waste valorization. *Current Opinion in Green and Sustainable Chemistry*, 8, 18–23. https://doi.org/10.1016/j.cogsc.2017.07.007

Mikucka W., Zielinska M., Bulkowska K., Witonska I. (2022) Subcritical water extraction of bioactive phenolic compounds from distillery stillage. *Journal of Environmental Management*, 318, 115548. https://doi.org/10.1016/j.jenvman. 2022.115548

Petrosyan G.P. (1982). Guidelines for the chemical reclamation of soda solonetz solonchaks in the Ararat Plain of the Armenian SSR. VTR-S-19-82.-M.: 27 (in Russian).

Ranta S., Rastogi S., Kumar R. (2021). Current trends for distillery wastewater management and its emerging applications for sustainable environment. *Journal of Environmental Management*, 290, 112544. https://doi.org/10.1016/j.jenvman.2021.112544.

Sahakyan S., Yedoyan T., Sukiasyan R., Baghdagyulyan A., Bakunts S. (2023). Basic Issues of Brandy Industry Waste Conservation. *Geomatics and Environmental Engineering,* 17(5), 45–60. https://doi.org/10.7494/geom.2023.17.5.45.

Sherwood J. (2020). The significance of biomass in a circular economy. *Bioresource Technology*, 300, 122755. https://doi.org/10.1016/j.biortech.2020.122755.

Toop T.A., Ward S., Oldfield T., Hull M., Kirby M.E., Theodorou M.K. (2020). AgroCycle – developing a circular economy in agriculture. *Energy Procedia*, 123, 76–80. https://doi.org/10.1016/j.egypro.2017.07.269.