American Journal of Biology and Natural Sciences
https://biojournals.us/index.php/AJBNS
ISSN: 2997-7185

Article

Effectiveness of Phytomeliorative Measures on Salinized Lands of Southern Karakalpakstan

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Abstract: This article provides a scientific assessment of the effectiveness of phytomeliorative measures on saline and degraded soils in Southern Karakalpakstan — using the example of Tortkul, Beruni, Ellikqala, and Amu Darya districts. Based on field experiments (2021–2024), it was determined that after planting phytomeliorative crops (camelthorn — **Alhagi pseudalhagi**, black saxaul — **Haloxylon aphyllum**, sand rice grass — **Psammochloa villosa**, tamarisk — **Tamarix ramosissima**), soil salinity decreased by 38–56%, the groundwater level dropped by 1.2–2.4 m, and biomass yield reached 3.2–6.8 t/ha. Experiments proved that phytomelioration produces the highest efficiency when combined with comprehensive agrotechnical and hydromeliorative measures. The obtained results have practical significance for addressing desertification and salinization problems in the Aral Sea basin.

Citation: Abatbay Uli, B. B. Effectiveness of Phytomeliorative Measures on Salinized Lands of Southern Karakalpakstan. American Journal of Biology and Natural Sciences 2026, 3(6), 98-102.

Received: 20th Apr 2026
Revised: 05th May 2026
Accepted: 25th May 2026
Published: 10th Jun 2026

Keywords: Phytomelioration, Salinization, Soil Degradation, Karakalpakstan, Camelthorn, Black Saxaul, Aral Sea Basin, Biological Reclamation, Salt Regime

Introduction

Soil salinization is one of the most serious environmental problems in the agricultural sector, affecting more than 1 billion hectares worldwide [1]. In the Central Asian region, this problem is particularly acute, and the ecological crisis resulting from the drying of the Aral Sea has further expanded its scope. The Republic of Karakalpakstan in Uzbekistan is one such area.

In the southern districts of Karakalpakstan — Tortkul, Beruni, Ellikqala, and Amu Darya districts — saline lands account for 60–75% of total agricultural areas [2]. In these areas, the groundwater table is located 1.0–2.5 m from the surface, causing salts to rise to the soil surface through capillary action. As a result, severe and very severe salinization (chloride-sulfate type) is observed.

Traditional hydromelioration methods (leaching, drainage systems, subsurface drains) are resource-intensive and sometimes lead to negative ecological consequences, creating the need for alternative solutions. Phytomelioration — the use of halophytes (salt-tolerant plants) for the biological restoration of saline soils — is being increasingly applied worldwide [3].

Analysis of the scientific literature shows that comprehensive studies on the selection of local halophyte species, their adaptability to soil and climate conditions, and their interaction with agroclimatic factors in the saline lands of Central Asia are insufficient [4]. Moreover, specific experimental data on the combination of phytomelioration with hydromelioration and agrotechnical methods under the conditions of Southern Karakalpakstan are almost absent in the literature.

Therefore, the main aim of this study is to quantitatively assess the impact of phytomeliorative measures on soil salt regime, groundwater level, and biomass yield under the saline conditions of Tortkul, Beruni, Ellikqala, and Amu Darya districts in Southern Karakalpakstan.

The research objectives were: to identify the local species composition of halophytes and assess their degree of salt tolerance; to compare the effectiveness of individual and combined application of phytomeliorative measures; to monitor salt dynamics in soils under different reclamation methods; and to develop practical recommendations based on the obtained results.[5]

Materials and Methods

The research was conducted in four districts of the Republic of Karakalpakstan during 2021–2024. The total study area was 840 hectares. The climate is arid-continental: annual precipitation is 80–120 mm, summer temperatures rise to +42°C, and winter temperatures drop to –20°C. The irrigation water source is the Amu Darya River.

The initial groundwater level ranged from 0.8 to 1.8 m. Soil type — saline sierozems (chloride-sulfate and sulfate types). According to laboratory analyses, the total salinity level ranged from 0.8 to 3.6%, and groundwater mineralization was 8–24 g/L.[6]

The experiments were set up in four variants: V1 — control (no reclamation); V2 — only phytomelioration; V3 — phytomelioration + agromelioration (gypsum, organic fertilizer); V4 — phytomelioration + hydromelioration (leaching, drainage). Three replicates were provided for each variant. Experimental plot size: 50×50 m (0.25 ha). Total number of experimental units: 4 variants × 3 replicates × 4 districts = 48 plots.

Phytomeliorative crops: camelthorn (**Alhagi pseudalhagi** Bieb.) — a highly salt-tolerant low shrub; black saxaul (**Haloxylon aphyllum** Schrenk) — a tree-like plant that develops rapidly in desert conditions; sand rice grass (**Psammochloa villosa** Bor.) — a perennial grass resistant to wind erosion and salinity; tamarisk (**Tamarix ramosissima** Ledeb.) — a fast-growing shrub effective in lowering the groundwater level.[7]

Soil samples were taken at the beginning and end of each season (2 times per year) from the 0–30, 30–60, 60–100, and 100–150 cm layers. A soil water-salt extract (1:5) was prepared. Total soil salt content was determined gravimetrically (drying at 105°C). The ionic composition (Cl^-, SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+}) was analyzed in the laboratory using titrimetric and ICP-OES methods.[8]

Groundwater level was monitored every two weeks using electronic measuring instruments in stationary piezometer wells. Three piezometer wells were installed in each plot. Biomass yield was calculated by collecting and weighing plants from 1 m² sample areas.

Statistical analysis was performed using SPSS 26.0 with one-way and multi-way ANOVA. The reliability of differences between variants was assessed using Duncan's multiple range test at $p<0.05$. Correlation analysis was performed using Pearson's coefficient.[9]

Results

The Table 1. dynamics of soil salt content during the study period are presented in Table 1. In the control variant (V1), the salt content remained largely unchanged, with a tendency to increase in autumn-spring due to arid conditions. In variant V2 (only phytomelioration), over the four years the salt content in the topsoil layer (0–30 cm) decreased by an average of 38%. The combined variants — V3 and V4 — showed reductions of 47% and 56%, respectively.[10]

Table 1. Dynamics of soil salinity in phytomelioration variants (2021–2024)

Variant	Initial salinity, % (2021)	salinity 2022	salinity 2023	salinity 2024	Decrease , %
V1 — Control	1.82 ± 0.14	1.79 ± 0.12	1.85 ± 0.16	1.80 ± 0.13	+1.1 (increase)
V2 — Phytomelioration	1.76 ± 0.11	1.54 ± 0.10	1.32 ± 0.09	1.09 ± 0.08	38.1%
V3 — Phyto + Agro	1.84 ± 0.13	1.48 ± 0.10	1.18 ± 0.08	0.97 ± 0.07	47.3%
V4 — Phyto + Hydro	1.79 ± 0.12	1.32 ± 0.09	1.01 ± 0.07	0.79 ± 0.06	55.9%

Note: Data are presented as mean ± standard error. Decrease is calculated relative to the control variant. ANOVA, $p<0.05$.

District-wise analysis showed that Tortkul district had the highest initial salinity (2.14%), while Amu Darya district had relatively lower salinity (1.42%). After phytomelioration, a statistically significant decrease ($p<0.05$) was observed in all districts.

Table 2. Due to the transpiration activity of phytomeliorative crops, a significant contribution to the lowering of the groundwater level was observed. As seen in Table 2, in variant V2, the average groundwater level dropped by 1.2 m (from 0.82 m to 2.02 m) over 4 years, and in variant V4 by 2.4 m (from 0.85 m to 3.25 m). This was especially pronounced during the summer period when evapotranspiration activity was high.[11]

Table 2. Dynamics of groundwater level (average by district, m)

District	2021 (initial)	2022	2023	2024	Average decrease (m)
Tortkul	0.92 ± 0.18	1.24 ± 0.21	1.78 ± 0.19	2.14 ± 0.22	1.22
Beruniy	0.85 ± 0.15	1.18 ± 0.17	1.65 ± 0.20	2.08 ± 0.18	1.23
Ellikqal'a	0.78 ± 0.14	1.10 ± 0.16	1.55 ± 0.18	1.98 ± 0.19	1.20
Amu Darya	0.80 ± 0.13	1.22 ± 0.18	1.72 ± 0.17	2.18 ± 0.21	1.38
Average	0.84 ± 0.15	1.19 ± 0.18	1.68 ± 0.19	2.10 ± 0.20	1.26

Note: Data are for variant V2 (only phytomelioration). Average values from piezometer wells.

Table 3. Regarding biomass yield, the highest indicators were observed for black saxaul (*Haloxylon aphyllum*): 6.8 t/ha of dry biomass by the end of year 4. Camelthorn (*Alhagi pseudalhagi*) produced 4.2 t/ha, sand rice grass (*Psammochloa villosa*) 3.2 t/ha, and tamarisk (*Tamarix ramosissima*) 5.1 t/ha.

Table 3. Biomass yield of phytomeliorative crops (t/ha, dry weight)

Plant species	2021	2022	2023	2024	Average
Alhagi pseudalhagi	0.8 ± 0.1	1.6 ± 0.2	2.9 ± 0.3	4.2 ± 0.4	2.38
Haloxylon aphyllum	1.2 ± 0.2	2.8 ± 0.3	4.6 ± 0.4	6.8 ± 0.5	3.85
Psammochloa villosa	0.6 ± 0.1	1.2 ± 0.1	2.1 ± 0.2	3.2 ± 0.3	1.78
Tamarix ramosissima	0.9 ± 0.1	2.0 ± 0.2	3.4 ± 0.3	5.1 ± 0.4	2.85

Note: Mean of 5 sample plots per plant species. ± indicates standard error.

Correlation analysis revealed a strong negative relationship between the decrease in soil salt content and biomass yield ($r = -0.81$; $p<0.01$). That is, the lower the salt content, the higher the biomass yield.

Discussion

The results show that phytomelioration is proving to be a biologically effective method for the reclamation of saline soils. It is particularly noteworthy that in variant V4 (phytomelioration + hydromelioration), soil salinity was reduced by 56% within 4 years. This is consistent with the studies of Hasanuzzaman et al. [12], who also reported that the combined application of halophytes is more effective than isolated methods.

The root system of camelthorn (*Alhagi pseudalhagi*) can reach depths of 3–4 m, playing a physical-mechanical role in reducing the intensity of capillary rise by drawing down groundwater through transpiration. This mechanism aligns with the theoretical concept of Central Asian halophytes proposed by A. Ilyasov and B. Nazarov [13]. The highest biomass production of black saxaul (6.8 t/ha) is explained by its ability to actively photosynthesize even under dry, saline, and high-temperature conditions — a trait particularly suited to the climate of Karakalpakstan.

When comparing districts, the effect of phytomelioration was relatively slower in Tortkul district due to the highest initial salinity (2.14%). This result indicates that the integrated reclamation scheme should be adapted according to the initial salinity level. In Beruni and Amu Darya districts, a relatively faster drop in groundwater level was observed — presumably due to the local geomorphological situation (proximity of the Amu Darya water layers to the surface).

Limitations: the study is based on 4-year observation data; longer-term (10+ years) dynamics need to be investigated. Additionally, calculating economic efficiency — the cost of implementing phytomelioration and its economic impact on yield — is an important direction for future research. The sample size (n=48 plots) is statistically sufficient, but additional stratification by different soil profiles would further improve reliability.[14]

In general, phytomelioration, when applied not as an alternative to traditional leaching and drainage methods but as an integral part of a comprehensive biological-hydromelioration system, provides high ecological and agrotechnical efficiency under the conditions of Southern Karakalpakstan.[15]

Conclusion

Based on the conducted research, the following conclusions were drawn:

1. The use of phytomeliorative crops (camelthorn, black saxaul, sand rice grass, tamarisk) on saline lands of Southern Karakalpakstan reduced soil salt content by 38–56% within 4 years. The highest efficiency was observed in combination with hydromelioration (variant V4).
2. Phytomeliorative crops allowed lowering the groundwater level by 1.2–2.4 m. This indicator was particularly high for camelthorn and black saxaul — their deep root systems reduce groundwater quantity through transpiration.
3. Biomass yield reached the highest level for black saxaul (6.8 t/ha). All studied species are promising for commercial or forage use under arid conditions and saline soils.
4. Practical recommendation: For areas with initial salinity above 2.0%, it is recommended to first carry out leaching measures in the first season, then plant phytomeliorative crops. For moderately saline areas (0.8–2.0%), phytomelioration can be started directly.

5. The results of this study can serve as a scientific basis for the wide introduction of phytomelioration in the State Program for Land Reclamation in the districts of the Republic of Karakalpakstan for 2025–2030.

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